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Extension of low temperature emission test to Euro 6 diesel vehicles

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1 INTRODUCTION

The European Commission Regulation No 692/2008 of 18 July 2008 [1] together with the Regulation No 715/2007 of the European Parliament and of the Council of 20 June 2007 [2] set the regulatory framework for type-approval of motor vehicles with respect to emissions from light passenger and commercial vehicles (Euro 5 and Euro 6). In particular these regulations set the emission standards and the related implementing measures, divided into three different steps, that will enter into force between 2009 (Euro 5) and 2014 (Euro 6). However, the above mentioned Regulations leave open some issues regarding the Euro 5b and the Euro 6 emissions standards to be addressed and defined before the entry into force of these pieces of legislation.

The low temperature emission test (Type VI test, -7°C) is currently required only for vehicles with positive ignition engines. However the extension of the Type VI test to diesel vehicles is under consideration mainly because of the introduction of new technologies in diesel engines in order to comply with the Euro 5/Euro 6 emissions standards of which the efficiency in controlling emission may strongly depend on the ambient temperature. This is especially true for Exhaust Gas Recirculation (EGR) systems and after-treatment systems for Oxides of Nitrogen (NO_x) that are deactivated or not operate in cold weather conditions, may results in elevated NO_x emissions. The review should consider whether to extend the low temperature emissions test (Type VI test) to Euro 6 diesel vehicles and whether emission limit values should be introduced in the future.

2 BACKGROUND INFORMATION

This final report provides a picture of the low temperature emission performances of modern diesel vehicles. The main results of the experimental activity carried out at the Joint Research Centre (JRC) to investigate the behaviour at low temperature of mainly Euro 5/6 diesel passenger cars are here summarised and discussed.

The Type VI test (-7°C) and related procedure/limits date back to Euro 3/4 standards (Directive 98/69/EC [3]) and is currently applicable only to vehicles with positive ignition engines. There is no requirement regarding low temperature emissions for diesel vehicles in the current European emission legislation.

The Type I emission test (verification of the average exhaust emissions at ambient temperature after a cold start) is carried out by driving the vehicle over the entire New European Driving Cycle (NEDC), while the Type VI test is limited to the urban part of the same NEDC cycle (i.e. the first four UDC15 elementary cycle), which is commonly indicated as Urban Driving Cycle (UDC). This is a logical approach for gasoline vehicles since the majority of emissions are emitted during the first seconds after the cold start to reach value close to zero once the three way catalysts works at its full efficiency. Furthermore, only Carbon Monoxide (CO) and total Hydrocarbons (HC) emissions are regulated since the air/fuel ratio is expected to be on the rich side during the cold start. On the contrary, NO_x emissions are expected to be the most critical pollutant for diesel vehicles and, in respect to this, the NO_x emission performance over the Extra-Urban Driving Cycle (EUDC) may be also very important. For this reason the diesel vehicles investigated at the JRC have been tested using the whole NEDC cycle also at low temperature. In addition, in the low temperature test for gasoline vehicles the dynamometer settings are adjusted for a 10% decrease of the coast-down time, meaning a corresponding increase of the resistance to progress (alternatively the coast down times measured at a temperature of -7°C should be used). There is no obvious reason why this approach should not be adopted also for diesel vehicles and therefore the same rule has been applied for the low temperature emission tests on diesel passenger cars described in this report.

The available studies on emission performance of diesel engines at low temperatures suggest that increased CO and HC emissions in cold-start tests could be attributed to incomplete combustion near the cold cylinder walls during the warming up phase. Moreover, as all modern diesel vehicles are equipped with Diesel Oxidation Catalyst (DOC), CO and HC emissions may be not efficiently reduced until the DOC does not reach the light-off temperature. Nevertheless, as diesel engines have inherently low CO and HC emissions, the effect of low temperatures is expected to be less critical than for petrol engines that rely on an after-treatment device to keep these pollutants under control. As far as NO_x emissions are concerned, in the past diesel engines had to comply with much higher limits compared to the current standards and therefore the engines used to be much simpler. At the time the effect of the low temperature was considered not significant and mainly for this reason diesel engines have been historically excluded from the low temperature test. However, in order to comply with the more severe NO_x limits modern diesel engines are equipped with sophisticated emission control technologies that may have a reduced efficiency or even may not work at all at low temperatures. For example, increased emission levels could be expected at low ambient temperatures due to the decreased EGR rate or its deactivation in order to avoid water condensation. Furthermore, it is now well known that Selective Catalytic Reduction (SCR) systems needs temperatures of the exhaust gas above certain values (typically 250°C) and therefore it is very likely that at low temperature these systems will start working much later than in tests carried out at temperatures > 20°C.

Research concerning cold start emissions of gasoline and diesel passenger cars has been conducted by Weilenmann et al. [4, 5]. They have measured – estimated the extra cold start gaseous emissions of gasoline and diesel vehicles. Vehicles ranging from old pre Euro 1 to Euro 4 have been tested for emissions at three different ambient temperatures (23, -7 and -20°C). They have also investigated the influence on cold start emissions of different driving conditions (e.g. urban, motorway) by testing the vehicles over various driving cycles. They conclude that for most of the pollutants the evolution of the cold start emission excess is not linear with the ambient temperature. The majority of CO and HC emissions of gasoline vehicles are emitted during the cold start phase and the emission levels increase with lower ambient temperatures. At -20°C the CO and HC emissions were respectively up to 15 and 35 times higher than at 23°C. In contrast, no evident trend was detected for NO_x emissions of the same vehicles. Cold start CO and HC emissions of diesel vehicles are significantly lower than those of gasoline ones. The cold start NO_x emissions of diesel vehicles depend on their certified emission level. Vehicles up to Euro 2 emission level exhibit low cold start NO_x emissions, with no clear dependence on ambient temperature for all the tested vehicles. The situation is different for Euro 4 diesel vehicles for which there is an evident increase in NO_x emissions as the temperature decreases. The authors explain this increase due to the higher friction and consequently higher engine loads at low temperatures.

Laurikko [6, 7, 8] has been evaluating the cold start emission performance of new passenger cars since 1993. Each year a batch of 10 to 20 vehicles has been tested at -7°C, according to the European as well as to the United States low ambient temperature test procedure. He concludes that for gasoline vehicles the average cold start CO emissions have decreased by more than 50% going from Euro 2 to Euro 4, while total HC emissions have improved less (30%). Diesel vehicles have also tested for their cold start emission performance. In general they emit almost one order of magnitude lower CO and HC emissions comparing to gasoline vehicles, with the worst performing diesel cars close to the best performing gasoline cars.

3 SCOPE AND OBJECTIVES OF THIS STUDY

The JRC has carried out a study with the main objective of providing data for the discussion on a possible extension of the low temperature emission test (Type VI test) to diesel vehicles. The study was mainly based on an experimental investigation of regulated emissions from a range of Euro 5 diesel vehicle/engine technologies tested at the JRC Vehicle Emission Laboratories (VELA). The test fleet included also a Euro 4 and a Euro 6 vehicle, the latter one equipped with a SCR NO_x after-treatment system.

4 TESTS CARRIED OUT AT THE JRC

In this chapter the results of emission tests carried out in the JRC's VELA laboratory both at ambient and low temperature on a range of recent diesel vehicles are presented.

4.1 TEST VEHICLES

Table 1 provides the main characteristics of the diesel vehicles tested at the JRC. All the tested vehicles were equipped with engines based on the Common Rail Direct Injection (CR-DI) technology. Vehicle 1 was certified as Euro 4. Vehicles 2 – 4 complied with the Euro 5 emission limits, while Vehicle 5 had been certified for the Euro 6 standards.

The type of exhaust after-treatment system installed on each vehicle was, as expected, dependent on the emission standards for which the vehicle was certified. Vehicle 1, a Euro 4 passenger car, was equipped only with a DOC while Vehicles 2 – 4, complying with the stricter Euro 5 standards, were equipped with both a DOC and a Diesel Particulate Filter (DPF). Finally, the Euro 6 compliant car (Vehicle 5) was equipped with a DOC, a DPF and a SCR system, the latter for NO_x emission reduction.

All vehicles featured quite low mileage. The vehicle with the highest mileage was Vehicle 5 that had accumulated about 22300 km at the beginning of the testing period.

The Carbon Dioxide (CO_2) emission values declared by the manufacturer (type approval data) are also provided.

All the vehicles were tested with the market fuel according to the Directive 2009/30/EC [9].

Table 1 – Vehicles' data and specifications.

Vehicle	Emission Standard	Injection system	Engine	Mileage [km]	Manufacturer's CO_2 emission [g/km]
Vehicle 1	4	CR-DI	1248cc 55kW	7966	110
Vehicle 2	5	CR-DI	1995cc 130kW	4667	128
Vehicle 3	5	CR-DI	1598cc 55kW	10978	109
Vehicle 4	5	CR-DI	1248cc 55kW	6402	108
Vehicle 5	6	CR-DI	1968cc 105kW	22284	155

4.2 INSTRUMENTATION DETAILS

The emission tests were carried out in a test cell equipped with a chassis dynamometer and a Constant Volume Sampling (CVS) system. The measurements were performed according to the current legislative procedures for type approval (UNECE Regulation 83 [10]). However the Type VI test performed at -7°C is not currently required for diesel passenger cars and as a consequence no procedure is defined in the legislation for this kind of vehicles. It was therefore decided to use the same procedure prescribed for gasoline cars with an important difference: In this case the vehicles were tested over the full NEDC cycle instead of only over the urban part of this cycle as currently required by the legislative procedure. In addition to the currently regulated pollutants at low temperature for gasoline vehicles (CO and HC), NO_x and particulate emissions were also measured. The bag gaseous emissions were available for the whole cycle as well as for the urban and extra-urban parts of the driving cycle (UDC and EUDC respectively).

The measurements were conducted in the VELA 2 test cell of JRC vehicle emission laboratory. The CVS was equipped with four critical orifices that allow the selection of the most appropriate flow rate from a minimum of 3.1 m^3/min to a maximum of 30.8 m^3/min. For this testing programme a CVS flow rate of 6 m^3/min was selected.

A Horiba MEXA-7400HTR-LE analyzer bench was employed for bag gaseous emission measurement (Oxides of Nitrogen (NO_x), total Hydrocarbons (HC), Carbon Monoxide (CO) and Carbon Dioxide (CO_2)). In addition, second by second data of emission concentrations in the raw exhaust were also recorded. The real time traces of Oxygen (O_2), CO_2, CO and HC provided the means for the calculation of lambda.

The roller bench of the chassis dynamometer was a single roller type manufactured by MAHA GmbH with the following characteristics:

- Diameter: 48”
- Inertia range: 454 – 45000 kg
- Maximum speed: 200 km/h

As far as the dynamometer’s settings are concerned, the dynamometer loads prescribed by the legislation were used (Type I test, 22°C) since the actual road coast down data were not available for these vehicles.

For the low temperature test (Type VI, -7°C) the dynamometer loads were increased by 10% as required by the legislation for gasoline vehicles, since no coast down data measured at -7°C was available.

The use of the dynamometer loads prescribed by the legislation instead of the road coast down data may affect significantly the emission results since the rolling resistance provided by the Regulation 83 in general underestimates the resistance to progress of the vehicle at low speeds and overestimates it at high speeds. Compared to a test performed using the actual road coast down data, the use of the dynamometer loads prescribed by the legislation may result in higher CO_2 and NO_x emissions especially over the extra-urban part of the cycle while CO and HC are usually affected to a lesser extent. In fact CO and HC are mostly emitted during the cold start on which the chassis dynamometer settings have a limited influence considering also the low speeds and the relatively soft accelerations involved in the first seconds of the NEDC cycle.

The vehicle to vehicle variability should be taken into consideration as well when evaluating the results.

As a consequence, the emission values presented in the following sections may be different from those measured by the manufacturer at the type approval for Type I test; nevertheless the trends and the general picture should not change significantly.

4.3 DRIVING CYCLE

All the vehicles were tested using the standard New European Driving Cycle shown in Figure 1. This cycle has been used in Europe for certification of light-duty vehicles since 2000 and consists of the urban part, commonly indicated as Urban Driving Cycle (UDC), which includes four repetitions of the Elementary Urban Cycle, and the Extra-Urban Driving Cycle (EUDC).

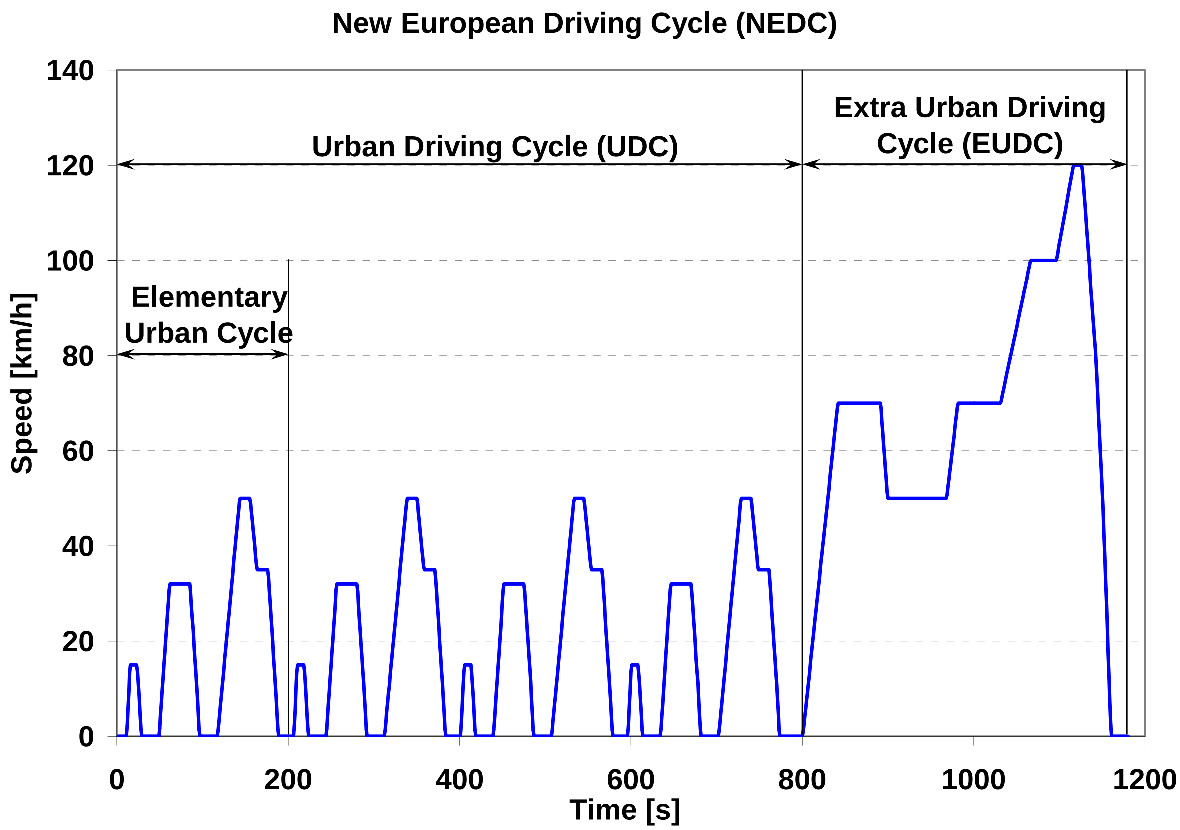


Figure 1 – New European Driving Cycle (NEDC) and its two phases: Urban (UDC) and Extra-Urban (EUDC).

4.4 TEST RESULTS

The results of the emission tests carried out on each vehicle at 22°C and -7°C are provided in this chapter. All the emission data shown is the average of at least two repetitions. The results presented here are referred to tests during which DPF regeneration did not occur.

VEHICLE 1

Table 2 provides the average bag values of regulated emissions and fuel consumption for the first vehicle investigated.

Three different emission values are given per each test performed either at 22 or at -7°C: The emissions measured over the whole NEDC cycle, the emissions measured over the urban part of the cycle (UDC) and the emissions measured over the extra-urban part (EUDC). Although in the case of gasoline vehicles only CO and total HC are currently regulated at low temperature, NO_x, and CO_2 emissions have been measured as well and are provided for all the tested vehicles.

The values given in parentheses refer to the type approval values (where available, only for Type I test at 22°C). The type approval emission data have been retrieved from the Kraftfahrt-Bundesamt (KBA), the Germany’s Federal Motor Authority [11, 12]. The KBA regularly publishes fuel consumption and emission type approval values for new vehicles with national or EC type approval in order to be accessible to environmentally conscious citizens, in accordance with the EC-Directive 2003/4/EC [13].

The CO_2, NO_x and fuel consumption values measured at the JRC for this specific vehicle were higher than the type approval values. In addition to the natural variability of emissions even among cars of the same model, one of the reasons explaining the higher measured values is for sure the use of the dynamometer load settings prescribed by Reg. 83 which differ from the (unknown) values used for the type approval.

Table 2 – Measured emissions and fuel consumption for the Vehicle 1 over the NEDC (22°C) and UDC (22°C & -7°C) driving cycles (in parentheses the type approval data).

VEHICLE 1 (EU4)							
Emissions	**Unit**	**NEDC**	**UDC**	**EUDC**	**NEDC**	**UDC**	**EUDC**
			22°C			**-7°C**	
HC	g/km	0.024	0.052	0.007	0.125	0.244	0.055
CO	g/km	0.149 (0.150)	0.397	0.004	0.932	2.410	0.070
NO_x	g/km	0.190 (0.160)	0.274	0.140	0.784	0.962	0.680
$HC+NO_x$	g/km	0.213 (0.190)	0.326	0.147	0.908	1.206	0.735
CO_2	g/km	114.1 (110)	143.7 (137)	96.8 (95)	133.3	180.2	106.0
Fuel Consumption	l/100km	4.3 (4.2)	5.5 (5.3)	3.7 (3.6)	5.1	7.0	4.0
Particulate Matter	mg/km	17.6 (22)	21.4	15.3	39.7	53.1	31.9

Figure 2 shows the bag emission values for total HC, CO, CO_2 and NO_x at 22 and -7°C measured over the NEDC, UDC and EUDC driving cycles. The Euro 4 limits for CO and NO_x (0.5 and 0.25 g/km respectively) for Type I test (Category M – Passenger Diesel Vehicles) over the NEDC cycle are indicated by a red solid line in the plots. The CO_2 emission value over the NEDC cycle declared by the manufacturer (110 g/km) is indicated in the respective chart by a green solid line. The error bars represent the maximum and minimum measured value of at least two repetitions.

Vehicle 1 complied with the Type I test emission limits (test at 22°C, NEDC) as expected. In the test conducted at low ambient temperature (-7°C) total HC, CO and NO_x over the NEDC cycle increased by 5.3, 6.3 and 4.1 times respectively. The CO_2 emissions over the NEDC increased by 16.8%.

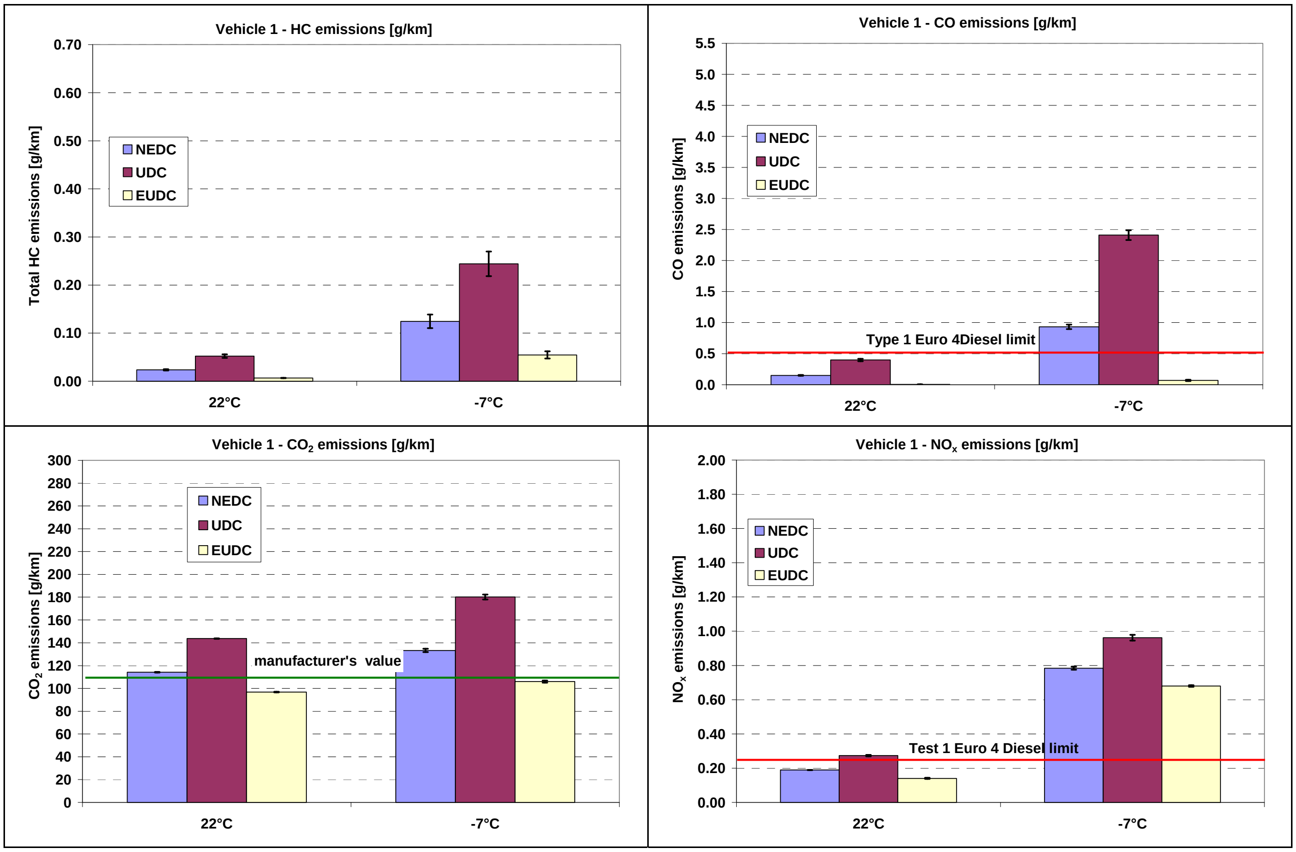


Figure 2 – Vehicle 1: Total HC, CO, CO_2 and NO_x bag emission values measured at 22°C and -7°C over the NEDC, UDC and EUDC driving cycles.

Figure 3 shows the gaseous instantaneous emissions and the calculated lambda value over the whole NEDC. Both at 22 °C and -7°C HC and CO emissions reached the highest levels during the first seconds of the driving cycle due to the cold start and to the oxidation catalyst not working at its full efficiency. The low ambient temperature (-7°C) has a clear impact on the performance of the oxidation catalyst, especially over the urban part of the cycle. For example, in the test at 22°C unburnt hydrocarbons were emitted over the whole cycle but the concentration dropped below 50 ppm after 400 seconds. In the low temperature test the concentration of total HC dropped below 50 ppm just over the last seconds of the cycle, when the vehicle's speed reached its maximum value. Also for CO the concentration was generally higher at -7°C with the exception of the extra-urban part where CO remained always at low levels. The higher emission CO and HC levels measured in the low temperature test are most probably entirely due to the colder catalyst compared to the 22°C test since other factors (e.g. the lower EGR rate at -7°C) should lead to a reduction of these pollutants.

Vehicle 1 was not equipped with any NO_x after-treatment system, as it is generally the case for all diesel vehicles up to the Euro 5 emission standards. In this case NO_x reduction is achieved with internal engine measures, such as EGR or injection timing adjustment. In the case of Vehicle 1, NO_x were emitted over the whole cycle with some evident spikes corresponding to the accelerations. At -7°C NO_x concentration resulted higher over all the cycle. The lambda value suggests that the air-to-fuel mixture became leaner (EGR deactivation?) in the low temperature test. Therefore, it is likely that the NO_x emissions increase was due to a different engine strategy followed in the low temperature test.

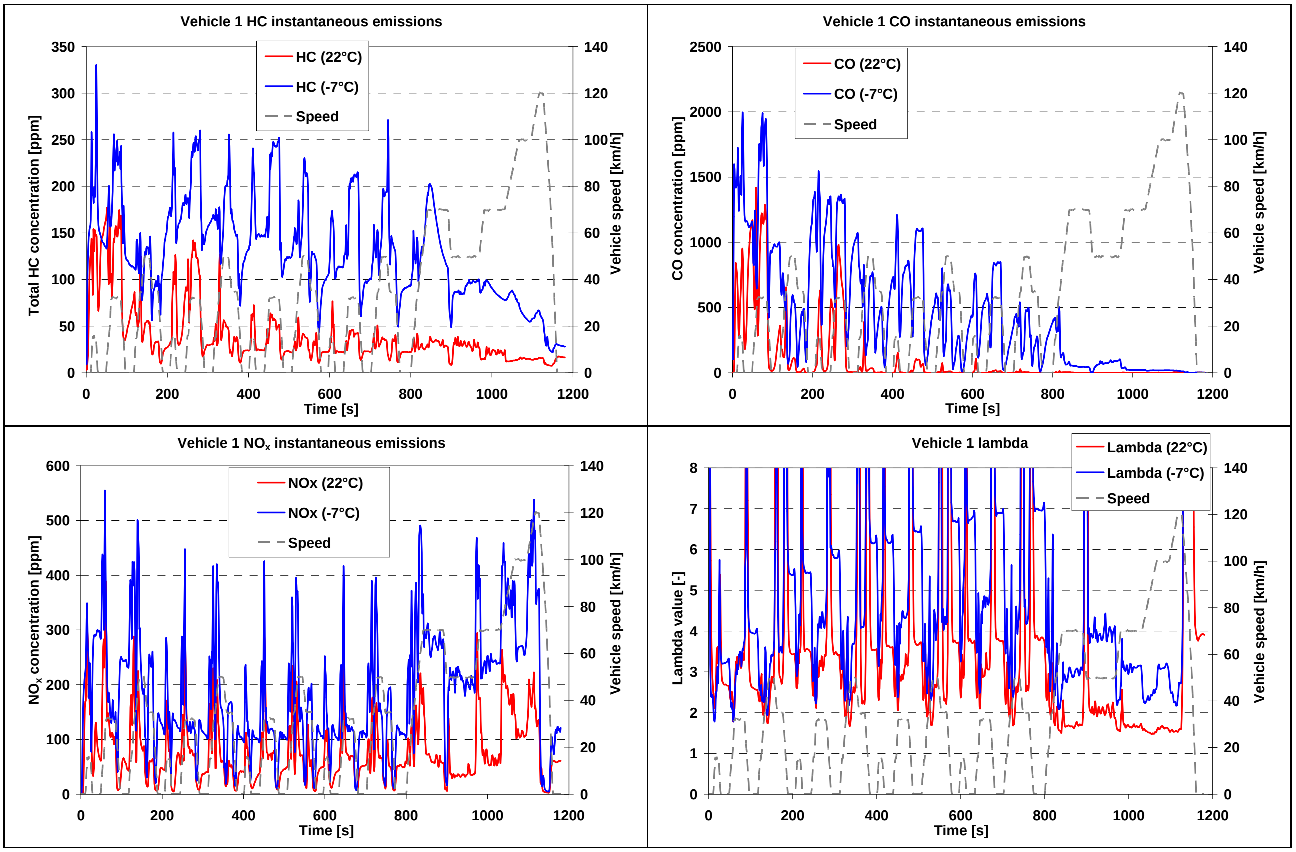


Figure 3 – Vehicle 1: Total HC, CO and NO_x instantaneous emissions and lambda value over the NEDC driving cycle at 22°C and -7°C.

Figure 4 shows the cumulative gaseous emissions of the same vehicle over the NEDC cycle at the two different test temperatures. This kind of chart is very helpful to investigate the different evolution of each pollutant over the whole cycle at both temperatures. The total mass of each pollutant increased several times in the -7°C test compared to the 22°C test. At 22°C the majority of CO mass was emitted over the first 300 s (cold start effect), while at -7°C the whole urban part of the cycle contributed to the much higher emission levels as it has already been discussed in Figure 3. The plot referred to NO_x emissions shows the importance of the contribution of the EUDC part to the total NO_x emissions with more than half of the total NO_x mass emitted over the last 400 s of the cycle.

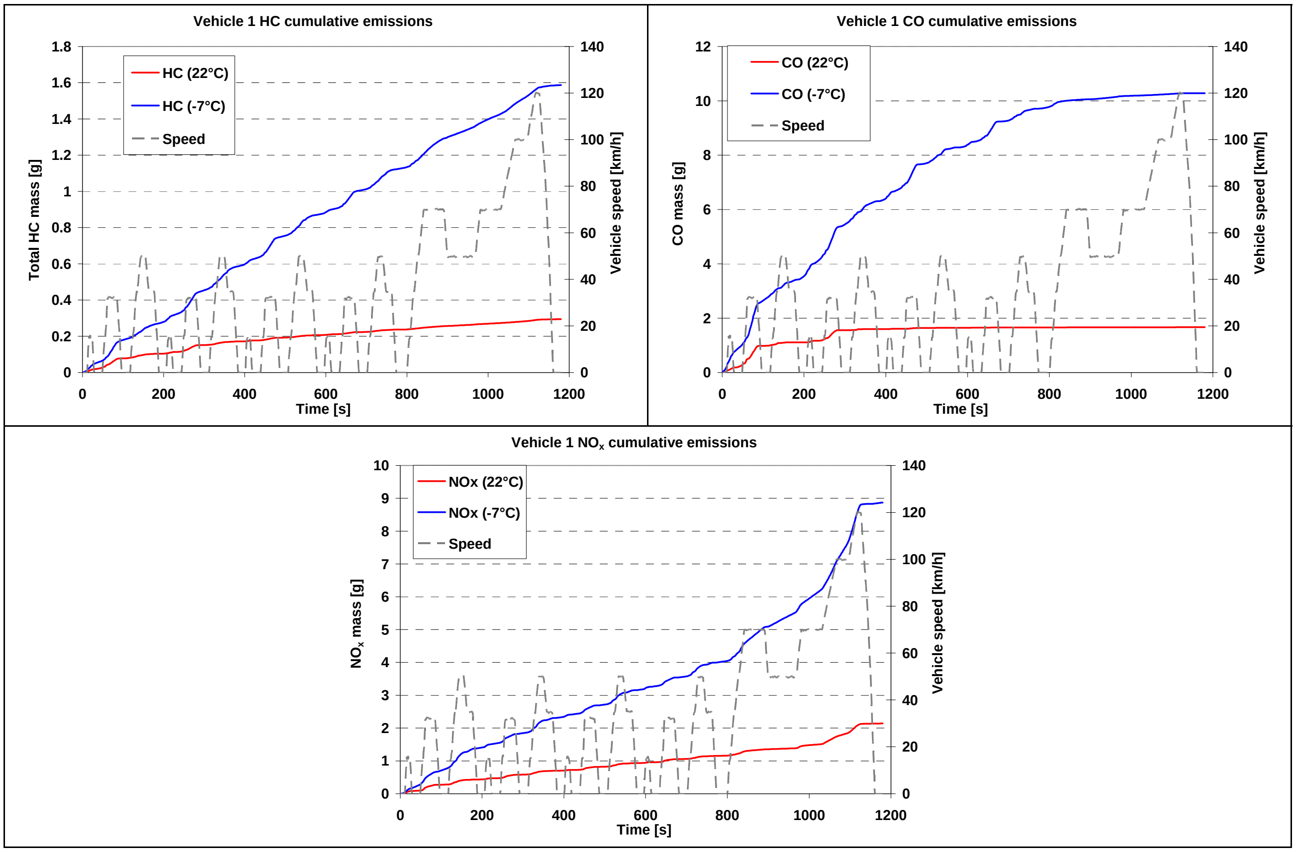


Figure 4 – Vehicle 1: Total HC, CO and NO_x cumulative mass emissions over the NEDC driving cycle at 22°C and -7°C.

VEHICLE 2

Table 3 provides the average bag emission values and the fuel consumption of Vehicle 2 over the NEDC, UDC and EUDC (22 & -7°C) driving cycles. The type approval CO, NO_x and $HC+NO_x$ values (from KBA database) for Type I test (22°C – NEDC), as well as the respective CO_2 and fuel consumption values are given in parentheses. In respect to this, there is a quite significant difference between the levels of NO_x and CO_2 measured at the JRC in the Type I test compared to the respective type approval values. Apart from the use of different dynamometer settings as already explained in paragraph 4.2, this difference could be partially attributed also to the fact that the engine start-stop system was disabled during the measurements at JRC/VELA laboratory in order to improve the repeatability of the tests. On the contrary, the CO measured value (0.071 g/km) was lower than the corresponding type approval value (0.413 g/km).

Table 3 – Measured gaseous emissions and fuel consumption for the Vehicle 2 over the NEDC (22°C) and UDC (22°C & -7°C) driving cycles (in parentheses the type approval data of Type I test at 22°C).

VEHICLE 2							
Emissions	**Unit**	**NEDC**	**UDC**	**EUDC**	**NEDC**	**UDC**	**EUDC**
			22°C			**-7°C**	
HC	g/km	0.014	0.031	0.004	0.067	0.130	0.029
CO	g/km	0.071 (0.413)	0.186	0.003	0.649	1.726	0.021
NO_x	g/km	0.180 (0.108)	0.246	0.141	1.084	1.933	0.589
$HC+NO_x$	g/km	0.194 (0.166)	0.277	0.145	1.151	2.064	0.618
CO_2	g/km	143.1 (128)	175.9 (161)	123.9 (109)	188.7	264.0	144.7
Fuel Consumption	l/100km	5.4 (4.8)	6.7 (6.4)	4.7 (4.1)	7.2	10.1	5.5
Particulate Matter	mg/km	0.387 (0.13)			0.706		

Figure 5 shows the gaseous emission values in bar chart format. Total HC, CO and NO_x emissions measured over the NEDC cycle at -7°C increased 4.9, 9.2 and 6 times respectively compared to the test carried out at 22°C. The CO_2 value measured over the NEDC at -7°C increased by 31.8% compared to the respective value measured in the 22°C test.

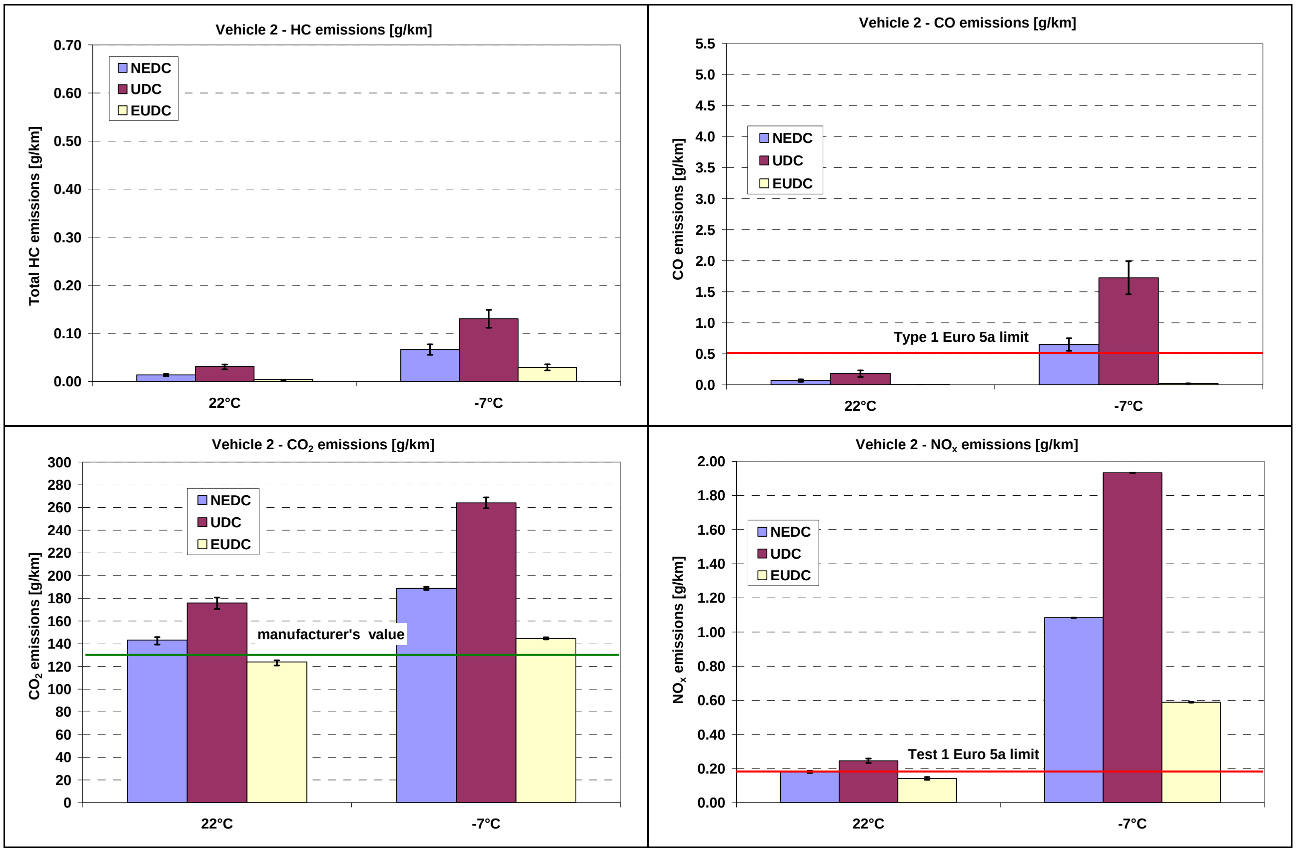


Figure 5 – Vehicle 2: Total HC, CO, CO2 and NOx emission measurements at 22°C and -7°C over the NEDC, UDC and EUDC driving cycles.

Instantaneous gaseous tail-pipe emissions were not available for the specific vehicle due to technical problems with the analyzers.

VEHICLE 3

Table 4 provides the bag gaseous emissions and the fuel consumption measured over the NEDC, UDC and EUDC (22 & -7°C) cycles for Vehicle 3.

The values in the parentheses (where exist) refer to the type approval values as retrieved from the KBA database. The CO_2 and fuel consumption measured values were higher than the type approval values, while CO, NO_x and HC+NO_x where in line with them.

Table 4 – Measured emissions and fuel consumption for the Vehicle 3 over the NEDC (22°C) and UDC (22°C & -7°C) driving cycles (in parentheses the type approval values).

VEHICLE 3							
Emissions	**Unit**	**NEDC**	**UDC**	**EUDC**	**NEDC**	**UDC**	**EUDC**
			22°C			**-7°C**	
HC	g/km	0.056	0.126	0.015	0.175	0.407	0.040
CO	g/km	0.283 (0.274)	0.752	0.010	1.118	2.970	0.048
NO_x	g/km	0.155 (0.174)	0.216	0.119	0.589	0.701	0.525
HC+NO_x	g/km	0.211 (0.213)	0.342	0.134	0.764	1.108	0.565
CO_2	g/km	127.2 (109)	154.2 (134)	111.4 (95)	150.8	197.4	123.8
Fuel Consumption	l/100km	4.8 (4.2)	5.9 (5.1)	4.2 (3.6)	5.8	7.7	4.7
Particulate Matter	mg/km	0.182 (0.6)	-	-	0.359	-	-
Particle Number	#/km	5.97×10^{8}	9.19×10^{8}	4.08×10^{8}	1.63×10^{11}	4.07×10^{11}	2.30×10^{10}

Figure 6 shows the bag emission values of Vehicle 3 measured at 22°C and -7°C in bar chart format. In the low temperature test, HC, CO and NO_x emissions measured over the NEDC cycle increased 3.1, 3.9 and 3.8 times respectively. The CO_2 emissions increased by 18.5%.

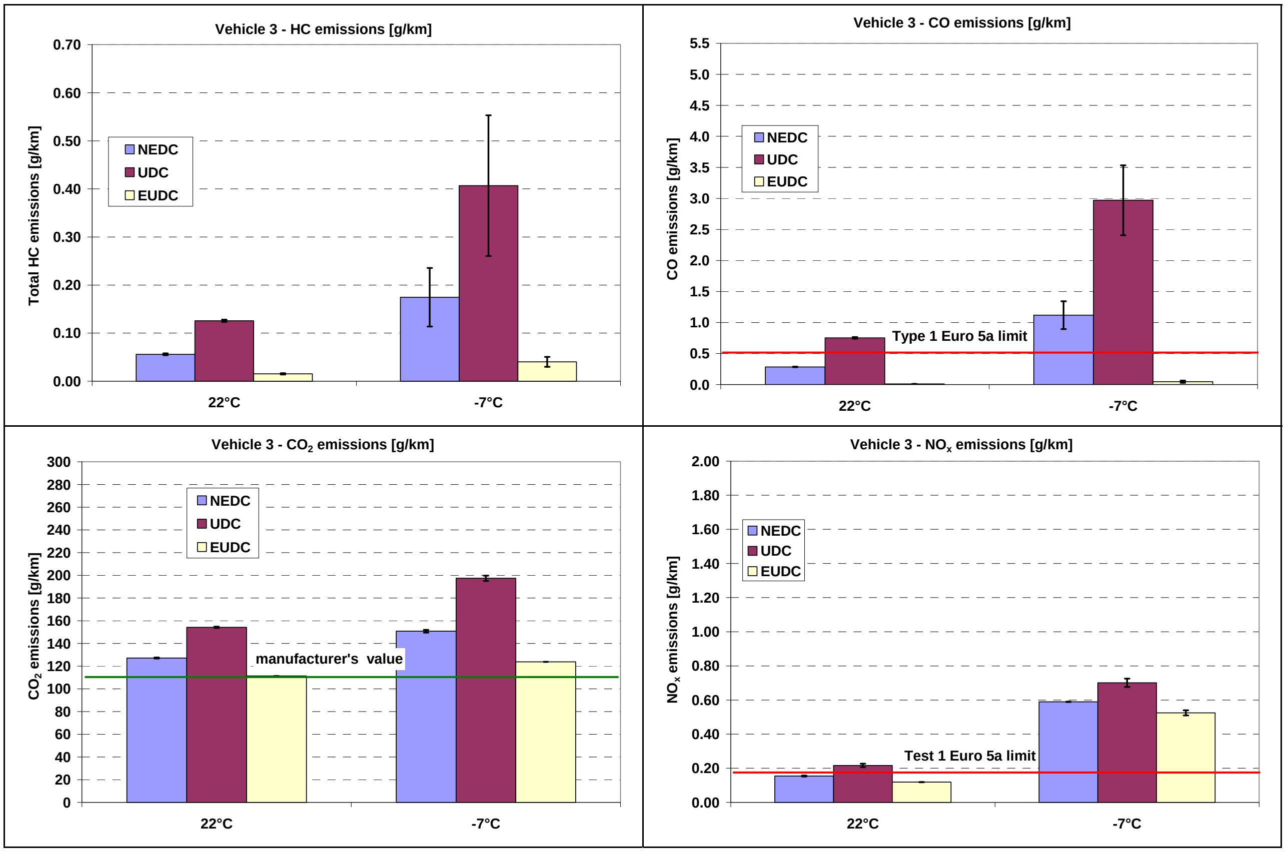


Figure 6 – Vehicle 3: Total HC, CO, CO_2 and NO_x bag emission values at 22°C and -7°C over the NEDC, UDC and EUDC driving cycles.

Figure 7 shows the instantaneous emission concentrations over the NEDC driving cycle at 22 and -7°C. At -7°C the concentration of each pollutant increased significantly compared to the test at 22°C. CO and HC concentration increased mainly over the cold start and the urban part of the cycle, while NO_x emissions increased all over the driving cycle but with the largest increase recorded over the extra-urban part.

In this case the lambda value decreased significantly in the -7°C test and this suggests a richer air/fuel mixture. Compared to Vehicle 1 this engine seems to follow a different strategy at low ambient temperature conditions. In general the lambda value of diesel engines varies according to the manufacturer's engine calibration and adopted strategy. The outcome in any case was similar, with significantly increased NO_x emissions.

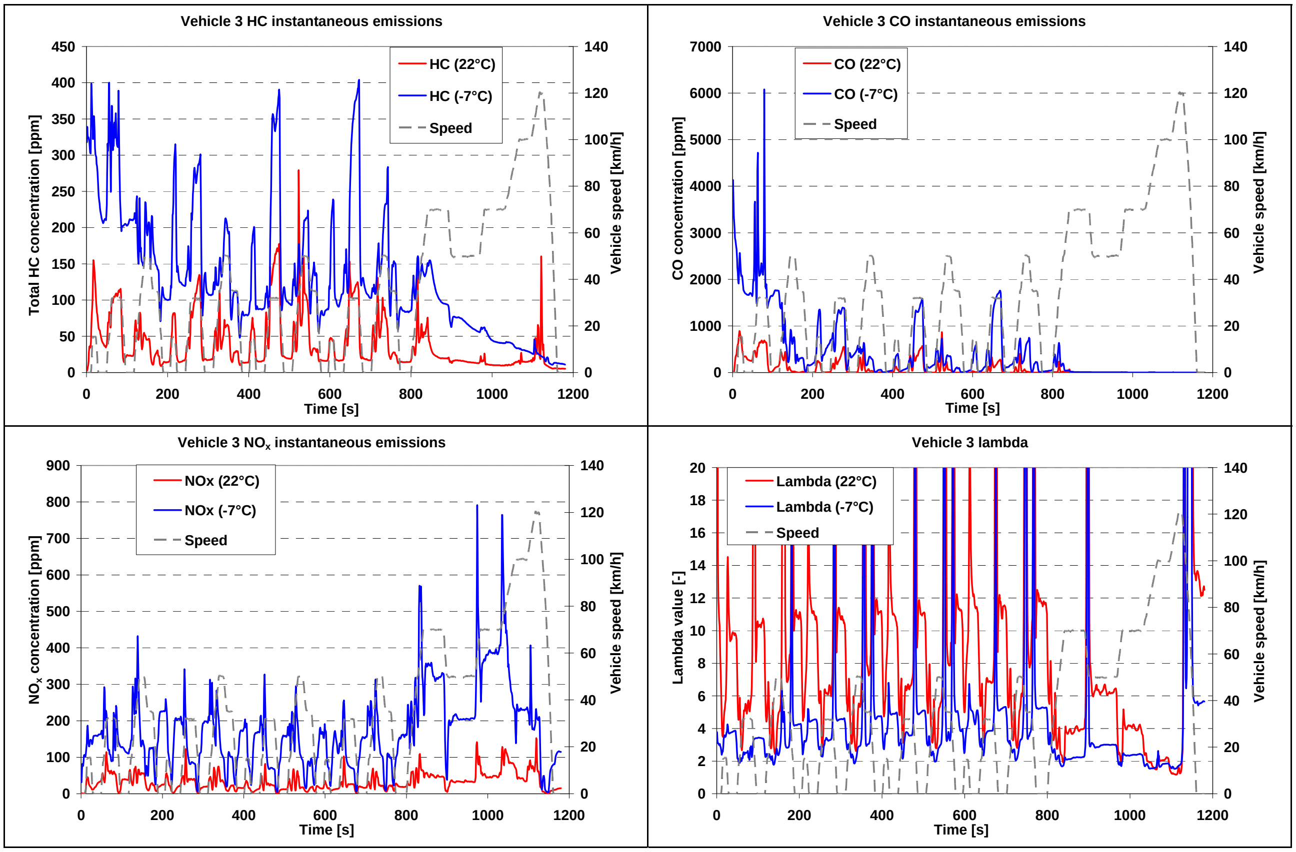


Figure 7 – Vehicle 3: Total HC, CO and NO_x instantaneous emissions and lambda value over the NEDC driving cycle at 22°C and -7°C.

The cumulative mass emissions of CO, HC and NO_x over the NEDC cycle at 22 and -7°C tests are presented in Figure 8. Total HC and NO_x increased over the whole cycle, while virtually no CO was emitted over the extra-urban part of the cycle. For all pollutants the total mass in -7°C test was between 3 and 4 times more than the test at 22°C.

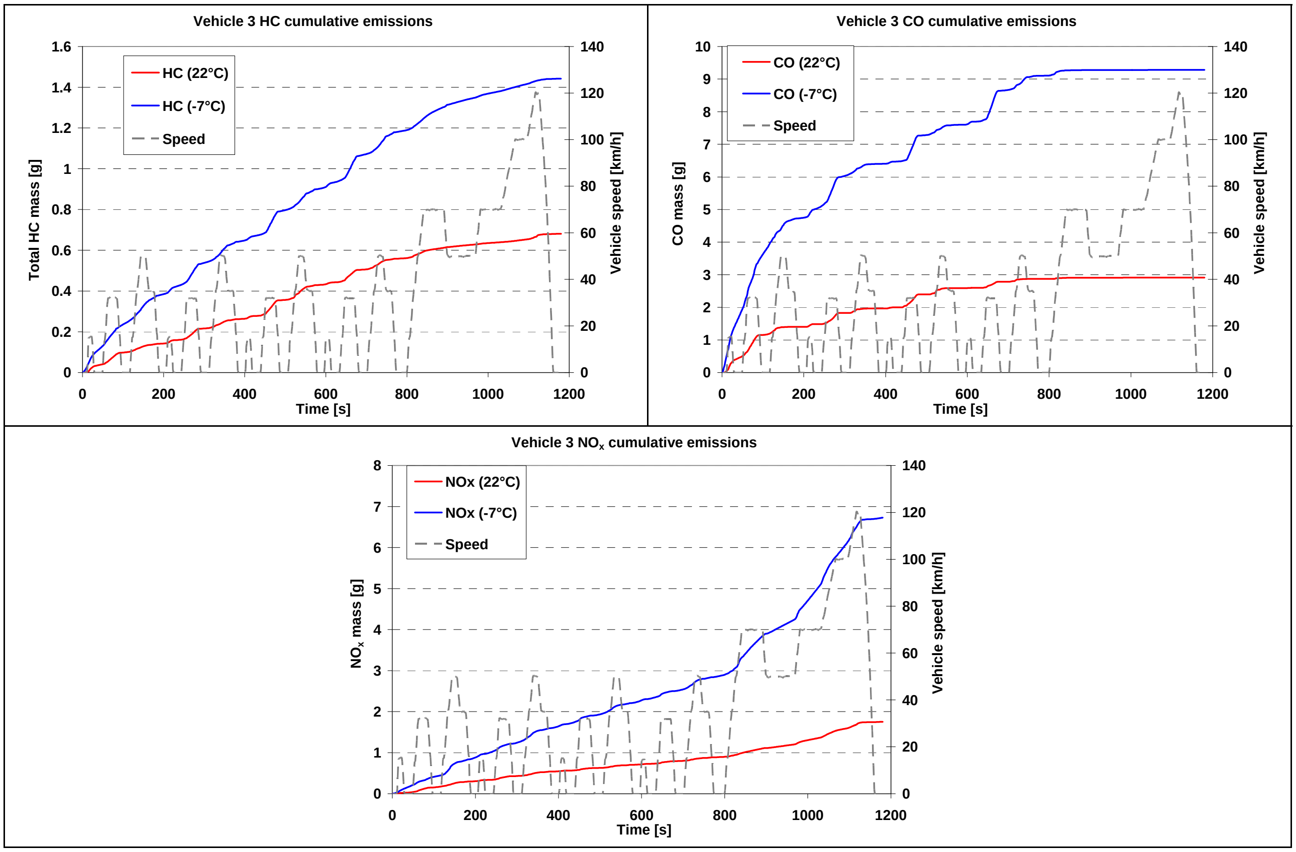


Figure 8 – Vehicle 3: Total HC, CO and NO_x cumulative mass emissions over the NEDC driving cycle at 22°C and -7°C.

VEHICLE 4

Table 5 provides the bag gaseous emission values of Vehicle 4. The results are referred to the NEDC, UDC and EUDC (22 & -7°C) driving cycles. The tests have confirmed that the vehicle complies with the relevant legislative limits. The values given in the parentheses represent the type approval data as reported in the KBA database. The differences with the JRC measurements are low, especially for NO_x emissions measured over the NEDC at 22°C. Again the measured CO_2 and fuel consumption values were higher than the type approval value, probably due to the different load settings and the deactivation of the start-stop system.

Table 5 – Measured emissions and fuel consumption for Vehicle 4 over the NEDC (22°C) and UDC (22°C & -7°C) driving cycles (in parentheses the type approval data).

VEHICLE 4							
Emissions	**Unit**	**NEDC**	**UDC**	**EUDC**	**NEDC**	**UDC**	**EUDC**
			22°C			**-7°C**	
HC	g/km	0.030	0.075	0.004	0.289	0.639	0.086
CO	g/km	0.238 (0.379)	0.644	0.000	2.006	5.213	0.135
NO_x	g/km	0.162 (0.165)	0.161	0.162	0.713	0.793	0.667
HC+NO_x	g/km	0.191 (0.216)	0.236	0.165	1.003	1.431	0.752
CO_2	g/km	128.0 (108)	154.7 (137)	112.5 (91)	148.2	188.0	124.9
Fuel Consumption	l/100km	4.9 (4.1)	5.9 (5.2)	4.3 (3.5)	5.8	7.5	4.8
Particulate Matter	mg/km	0.328 (1.0)	-	-	1.529	-	-
Particle Number	#/km	9.72×10^{10}	1.31×10^{11}	7.73×10^{10}	4.02×10^{10}	7.73×10^{10}	1.85×10^{10}

Figure 9 shows the bag emission values of this vehicle in bar chart format. In the -7°C test total HC, CO and NO_x emissions measured over the NEDC resulted respectively 9.7, 8.4 and 4.4 times higher than the values measured at 22°C. In the -7°C test the CO_2 emission value over the NEDC driving cycle increased by 15.7%.

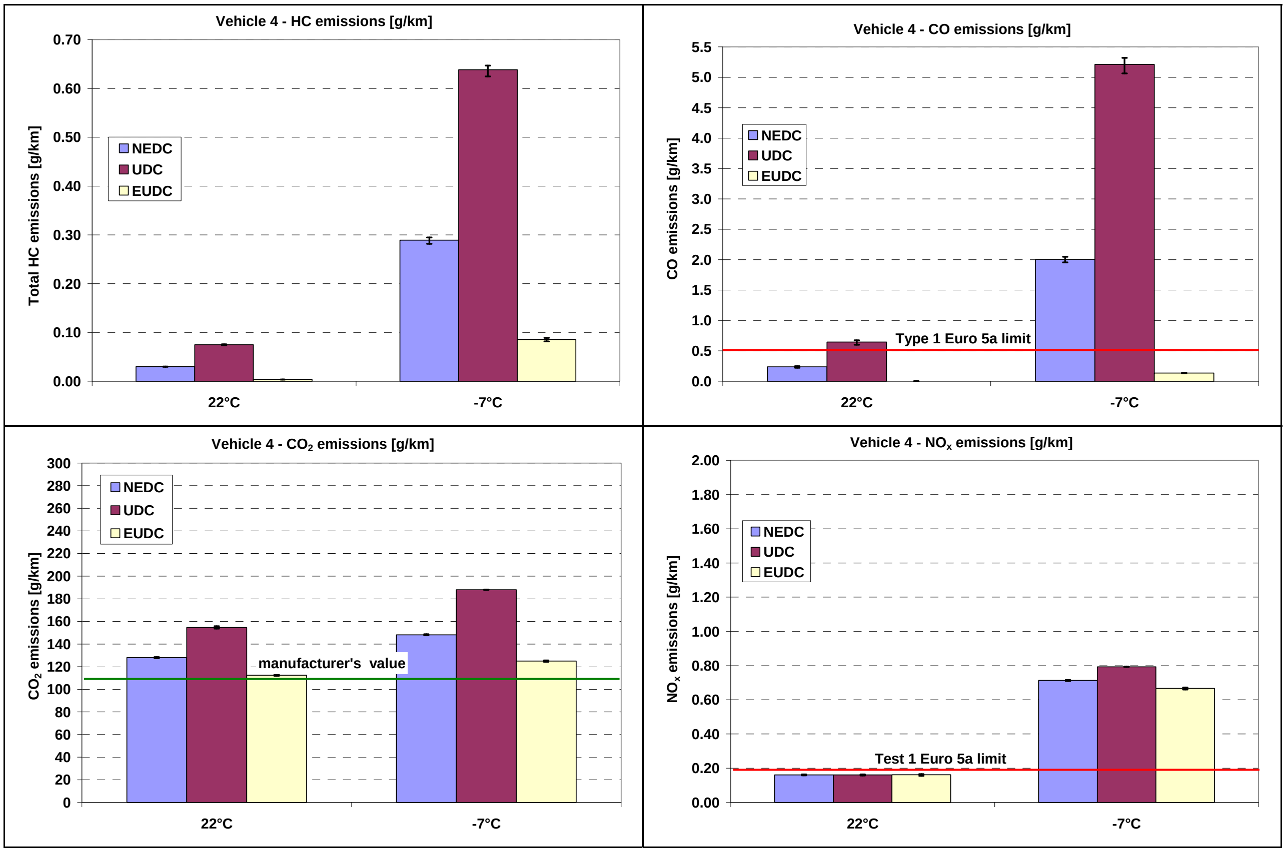


Figure 9 – Vehicle 4: Total HC, CO, CO_2 and NO_x measured bag emission values at 22°C and -7°C over the NEDC, UDC and EUDC driving cycles.

Figure 10 shows the instantaneous emissions for HC, CO and NO_x and the lambda value recorded over the NEDC driving cycle at the two test temperatures. In addition the applied EGR rate (in percentage) has been recorded from the ECU.

Looking at the HC and CO emissions pattern at 22°C, it is clear that after the DOC had warmed up the concentrations decreased near to zero. At -7°C the CO and HC concentrations were much higher probably due to the fact that the DOC worked less efficiently especially over the urban part of the cycle. This is confirmed by the exhaust temperature measured upstream of the oxidation catalyst shown in Figure 10 as well. In the test carried out at -7°C the exhaust temperature remained quite below the values recorded at 22°C, with a difference up to 50°C or even more. Over the EUDC part, although the exhaust temperature resulted lower in the low temperature test compared to 22°C, its value was probably high enough (180-350°C) to promote the oxidation of CO and HC. NO_x emissions showed a similar pattern for both the test temperatures but at -7°C the levels were higher. The NO_x emissions profiles can be explained with the recorded EGR rate. The plot clearly shows that in the low temperature test the EGR was deactivated during the first seconds of the cycle and that its rate decreased all over the cycle.

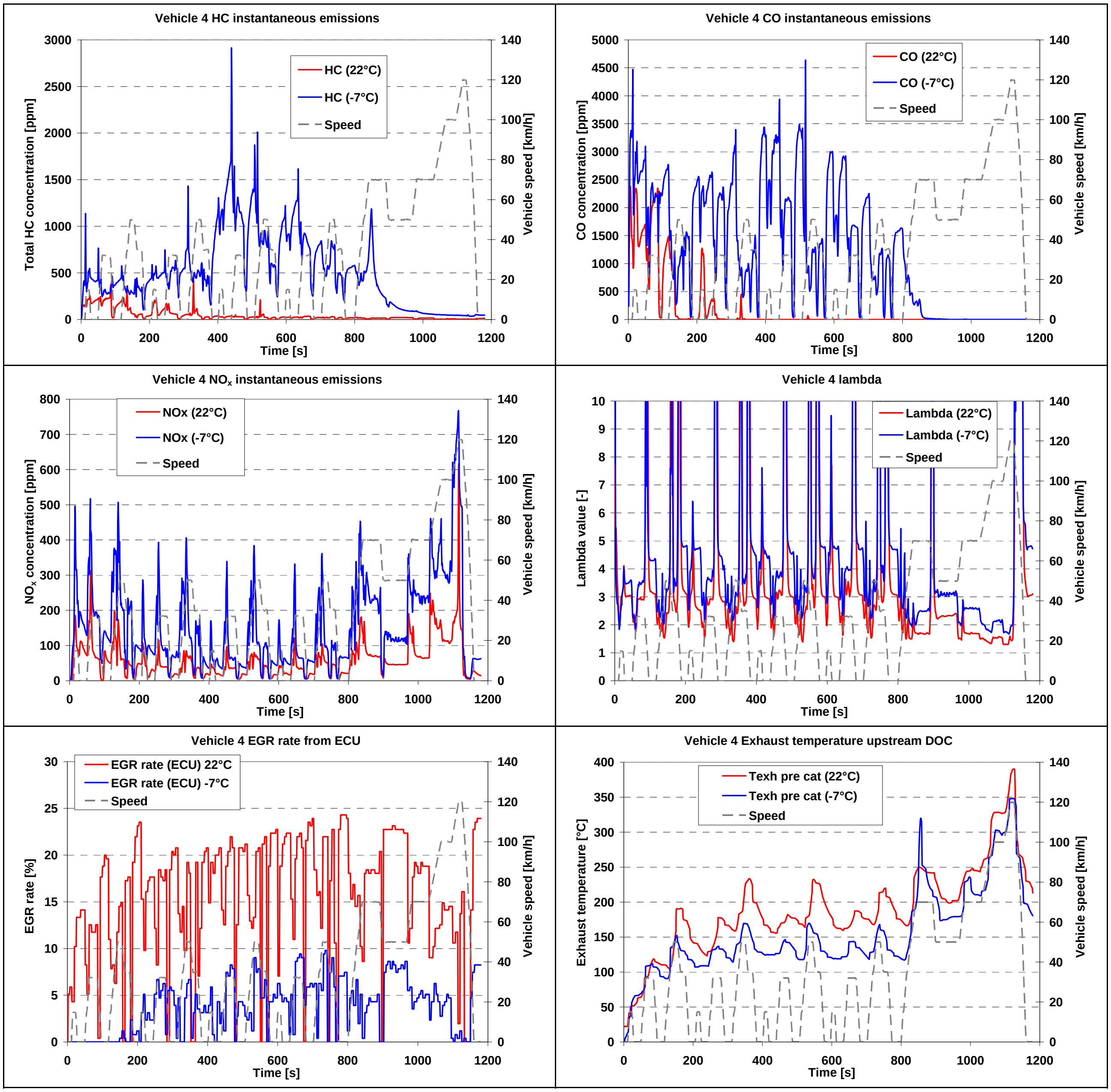


Figure 10 – Vehicle 4: Total HC, CO and NO_x instantaneous emissions, lambda value, EGR rate and exhaust temperature upstream of DOC over the NEDC driving cycle at 22°C and -7°C.

Figure 11 shows the cumulative emissions of HC, CO and NO_x over the NEDC cycle. The evolution of HC and CO emissions resulted to be very similar. At 22°C the majority of CO and HC emissions were emitted during the first 200 s of the cycle probably corresponding to the warming up phase of the catalyst. At -7°C it seems that only over the extra-urban part of the cycle CO and HC emissions were efficiently controlled by the catalyst, as already discussed above.

In the case of NO_x emissions the evolution of the cumulative emission curve turned out to be quite similar for the tests carried out at 22°C and -7°C, but at low temperature the overall quantity increased several times. Both the NO_x profiles recorded at the two different temperatures showed a very important contribution of the extra-urban part to the total emissions.

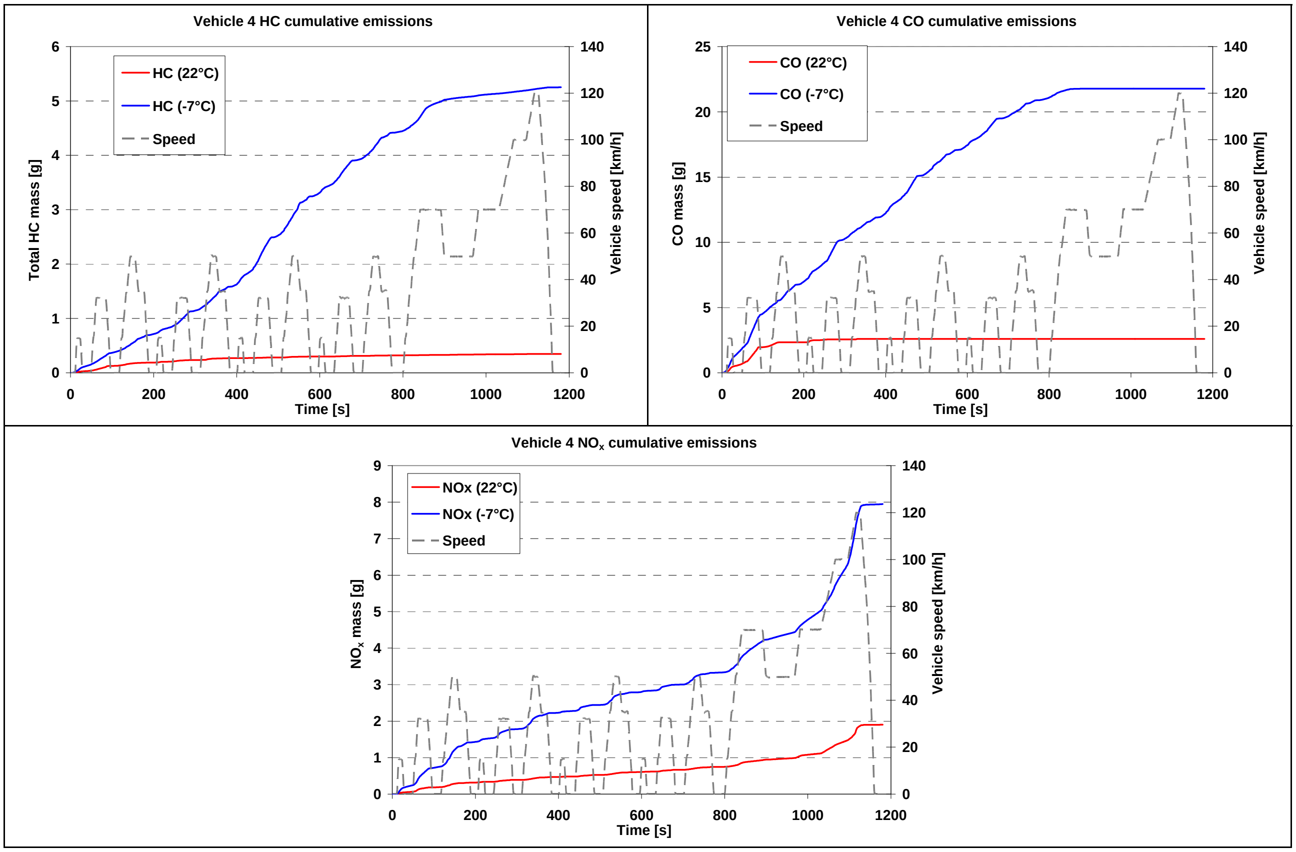


Figure 11 – Vehicle 4: Total HC, CO and NO_x cumulative mass emissions over the NEDC driving cycle at 22°C and -7°C.

VEHICLE 5

Table 6 provides the emission values and the fuel consumption measured over the NEDC, UDC and EUDC (22 & -7°C) cycles for Vehicle 5. The type approval values, where available, are given in parentheses. Measured CO emissions were lower than type approval value, while NO_x and CO_2 emissions were higher. Vehicle 5 was also equipped with a start-stop system, which was disabled during the measurements.

This vehicle was the only one among the examined vehicles been certified for the Euro 6 standards. As such it has to meet stricter NO_x emission limit (80 mg/km) compared to Euro 5 (180 mg/km). In order to comply with the stricter NO_x limit, Vehicle 5 was equipped with a NO_x after-treatment exhaust system. The technology chosen for this vehicle was the Selective Catalytic Reduction (SCR) based on the injection of urea in the exhaust gas.

Table 6 – Measured emissions and fuel consumption for Vehicle 5 over the NEDC (22°C) and UDC (22°C & -7°C) driving cycles (in parentheses data type approval data).

VEHICLE 5 (EU6)							
Emissions	**Unit**	**NEDC**	**UDC**	**EUDC**	**NEDC**	**UDC**	**EUDC**
			22°C			**-7°C**	
HC	g/km	0.012	0.026	0.005	0.006	0.015	0.001
CO	g/km	0.062 (0.162)	0.160	0.006	0.112	0.300	0.004
NO_x	g/km	0.067 (0.046)	0.162	0.012	0.367	0.821	0.104
$HC+NO_x$	g/km	0.079 (0.056)	0.187	0.017	0.373	0.836	0.105
CO_2	g/km	170.4 (155)	237.4 (200)	131.6 (129)	201.5	293.8	148.1
Fuel Consumption	l/100km	6.5 (5.9)	9.0 (7.6)	5.0 (4.9)	7.6	11.2	5.6
Particulate Matter	mg/km	0.393 (0.4)	-	-	0.581	-	-
Particle Number	#/km	$4.67x10^{10}$	$1.25x10^{11}$	$7.96x10^{8}$	$6.44x10^{11}$	$1.74x10^{12}$	$1.30x10^{10}$

Figure 12 shows the bag emission values measured over the NEDC, UDC and EUDC at the two different test temperatures in bar chart format. Vehicle 5 exhibited the lowest CO and HC emissions both at 22 and -7°C compared to all the other tested vehicles.

Also NO_x emissions measured at 22°C, as expected, resulted to be the lowest. However, when the test was conducted at -7°C the NO_x level increased 5.5 times. CO_2 emission increased by 18.3% in the low temperature test.

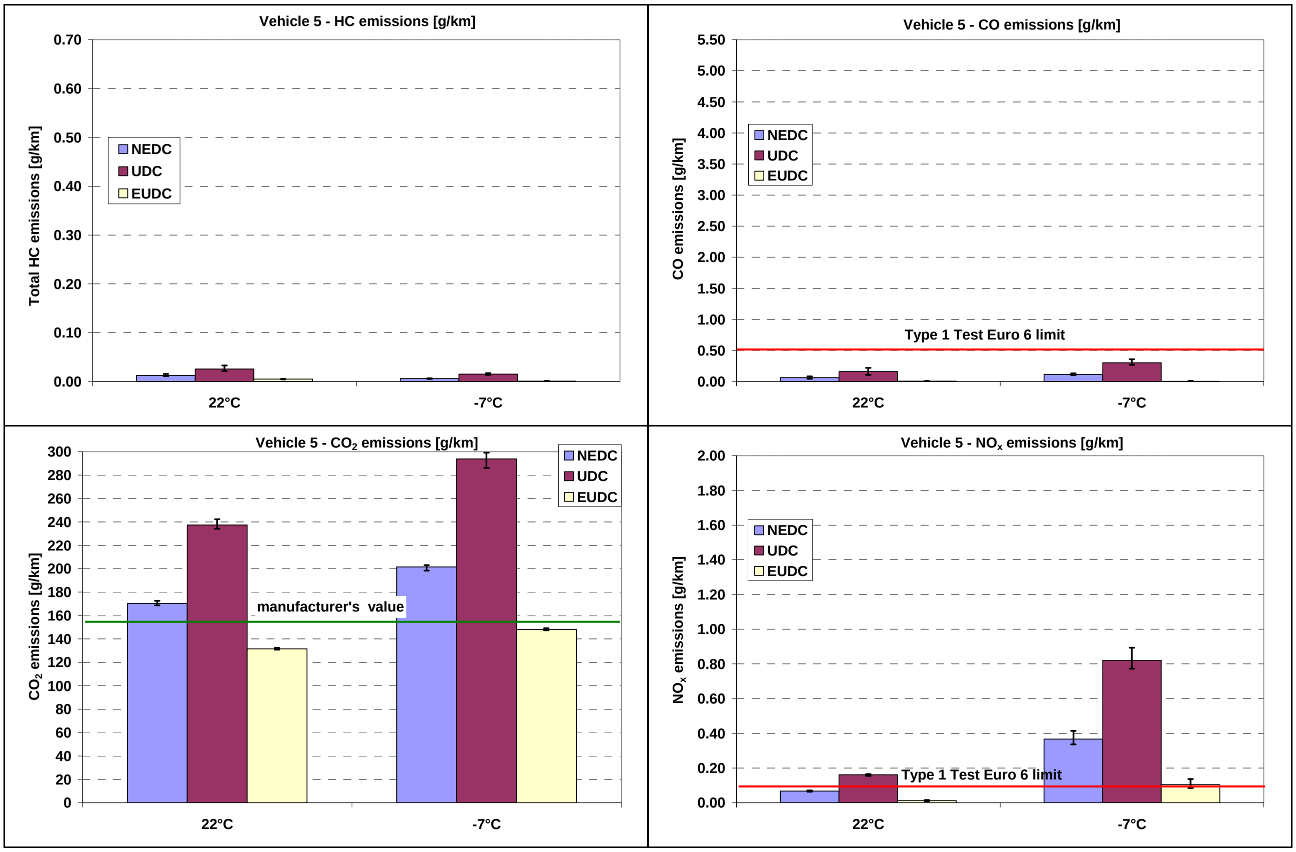
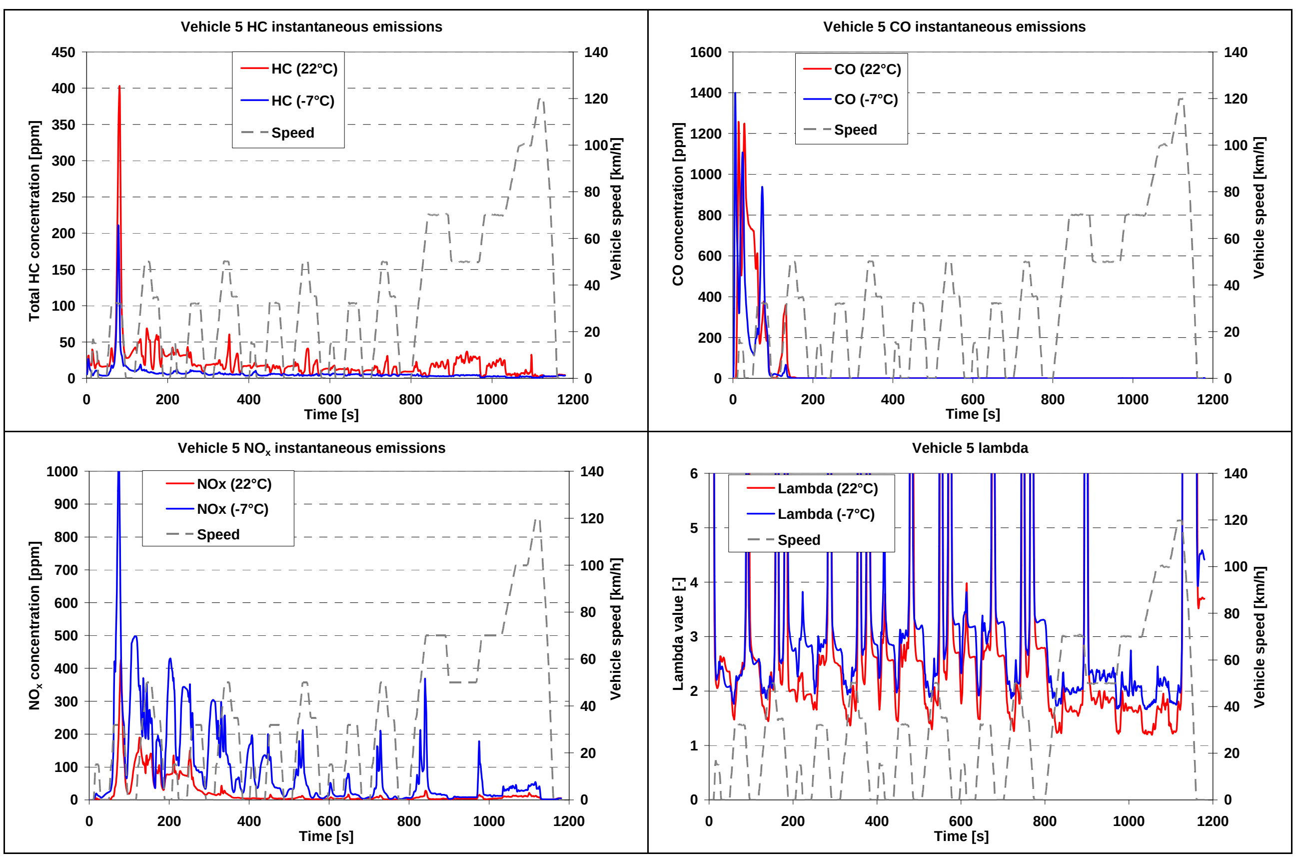


Figure 12 – Vehicle 5: Total HC, CO, CO_2 and NO_x emission measurements at 22°C and -7°C over the NEDC, UDC and EUDC driving cycles.

Figure 13 shows the second-by-second HC, CO and NO_x concentration values measured over the NEDC. The emission profiles of HC and CO recorded at 22°C and -7°C show little differences. At both the two test temperatures the CO concentration decreased to zero after 200 s, which probably correspond to the warming phase of the DOC that seems to have about the same duration. In fact Figure 13 shows that the evolution of the exhaust temperature upstream the after-treatment devices was very similar for the tests at 22°C and at -7°C until the time instant 250 s.

HC concentration was instead low over the first 50 s of the cycle, then a spike occurred at t = 80 s and then the concentration decreased again to low values. This peculiar behavior might be due to the exhaust after-treatment system (DOC or catalyzed DPF) having some HC storage capacity (e.g. zeolite): After the initial absorption phase (first 50 s) the stored hydrocarbons were released (time around 80 s) to be oxidized by the DOC's substrate that in the meanwhile should have been warmed up. Such catalyst formulations have been already studied for both gasoline [14, 15] and diesel vehicles combined also with NO_x emission reduction systems (Lean NO_x Trap [16], SCR [17]).

Concerning NO_x emissions, the second by second trace shows that at 22°C their concentration was reduced to low values (below 25 ppm) after the first 350-400 s of the cycle and then remained low for the rest of the test. This steep NO_x abatement could be due to the start of the injection of urea, the reactant needed to convert the NO_x to N_2 over the SCR system. It is in fact well known that urea is injected in the exhaust system only when the temperature is above certain values that depend on the configuration of the exhaust system. In a recent study a NO_x conversion in a SCR was reported ones the internal temperature of the converter reached approximately 180°C [18]. Interestingly the exhaust temperature recorded upstream of all the after-treatment devices rose very quickly between 150 and 300 seconds while the EGR was reduced to zero for a certain interval of time. This might be a specific strategy applied by the ECU on purpose in order to enable the SCR operation [19] as early as possible. In the -7°C test not only did the NO_x concentration decreased more slowly and reached low values much later, but several NO_x spikes were noticed next to each acceleration event until the beginning of extra-urban part of the cycle. This could be the result of a combination of different factors: First of all the engine out NO_x emissions were expected to be higher at -7°C as a consequence of the reduced EGR rate (shown in Figure 13) and the higher dynamometer loads (+10% compared to the test at 22°C). In addition, in the -7°C test the exhaust temperature turned out to be up to 50°C lower than at 22°C at least from the instant t ~300 s to ~800 s. Under such operating conditions, the ECU might have started injecting urea much later, resulting to reduced time of SCR operation. The increased NO_x engine out emission and the reduced time during which the SCR was working would explain the higher NO_x emissions especially over the UDC part. However, since the engine out emissions were not recorded it was not possible to establish when the SCR worked and therefore the above has to be considered as just one of the possible explanations.



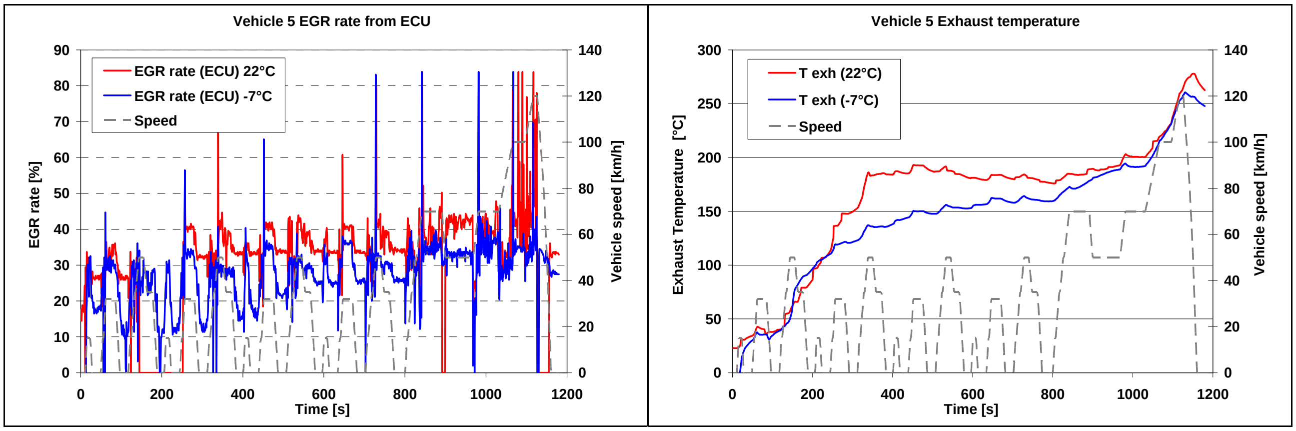


Figure 13 – Vehicle 5: Total HC, CO and NO_x instantaneous emissions, lambda value, EGR rate and exhaust temperature upstream of the after-treatment systems over the NEDC driving cycle at 22°C and -7°C.

The cumulative mass emissions for total HC, CO and NO_x over the NEDC cycle are shown in Figure 14. The evolution of CO was similar at both at 22°C and -7°C. Basically all the CO mass was emitted over the first seconds of the cycle during the cold-start. Unburned HC emissions were instead emitted throughout the whole test. In this case, it seems that more HCs were emitted at 22°C than at low temperature but in any case, the final mass remained in very low levels (~0.2 g maximum).

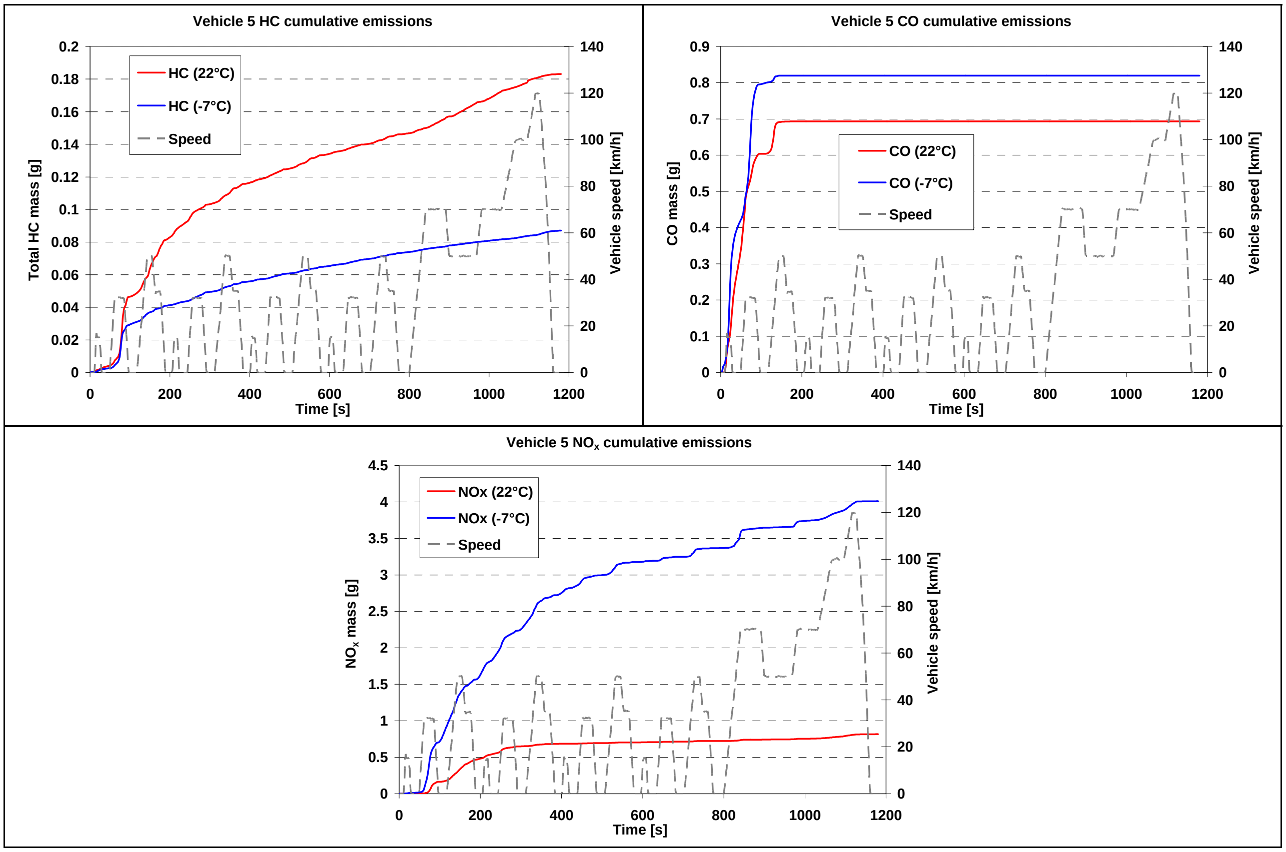


Figure 14 – Vehicle 5: Total HC, CO and NO_x cumulative mass emissions over the NEDC driving cycle at 22°C and -7°C.

4.5 OVERVIEW OF THE TESTS CARRIED OUT AT THE JRC

In this section an overview of the results of the whole testing programme is provided. The CO, total HC, NO_x and combined $HC+NO_x$ emissions measured over the NEDC at the two different test temperatures (22°C and -7°C) and with the different test vehicles are discussed and compared.

Figure 15 summarizes the results for CO emissions. In order to allow a direct comparison of the emission levels measured at the two different test temperatures the emissions over the UDC (left panel) and over the EUDC (right panel) are sown in the chart, under the same scale.

As already discussed in the previous chapters, most of CO is generally emitted immediately after the cold start during the warm up phase of the catalyst. For this reason the emission levels measured over the UDC are much higher than the values measured over the EUDC as clearly shown by Figure 15. As a consequence the effect of the test temperature is much more important for the urban part of the cycle while the emissions over the EUDC remain in any case at very low absolute values. According to the current legislation, the low temperature test for gasoline vehicles is limited to the urban part of the cycle (the vehicle is not driven over the EUDC) and obviously the regulatory limits for CO and HC in the Type VI test are referred to this part of the NEDC. In the case of CO the current emission limit valid for gasoline vehicles is 15 g/km, as also presented in Figure 15. The plot clearly shows that for all the tested vehicles the emission levels measured over the urban part of the cycle at -7°C were well below this limit (at least 65%). As far as the urban part of the cycle is concerned, Vehicle 2 resulted the car with the largest increase (9.3 times) in CO emissions while Vehicle 4 the car with the highest emissions (5.2 g/km). All the other tested vehicles remained below 2.97 g/km of CO over the UDC. The Euro 6 compliant Vehicle 6 exhibited the lowest CO emission levels and the lowest increase in low temperature conditions compared to all the other tested vehicles. However, only one Euro 6 compliant vehicle has been tested and therefore this result cannot be generalized.

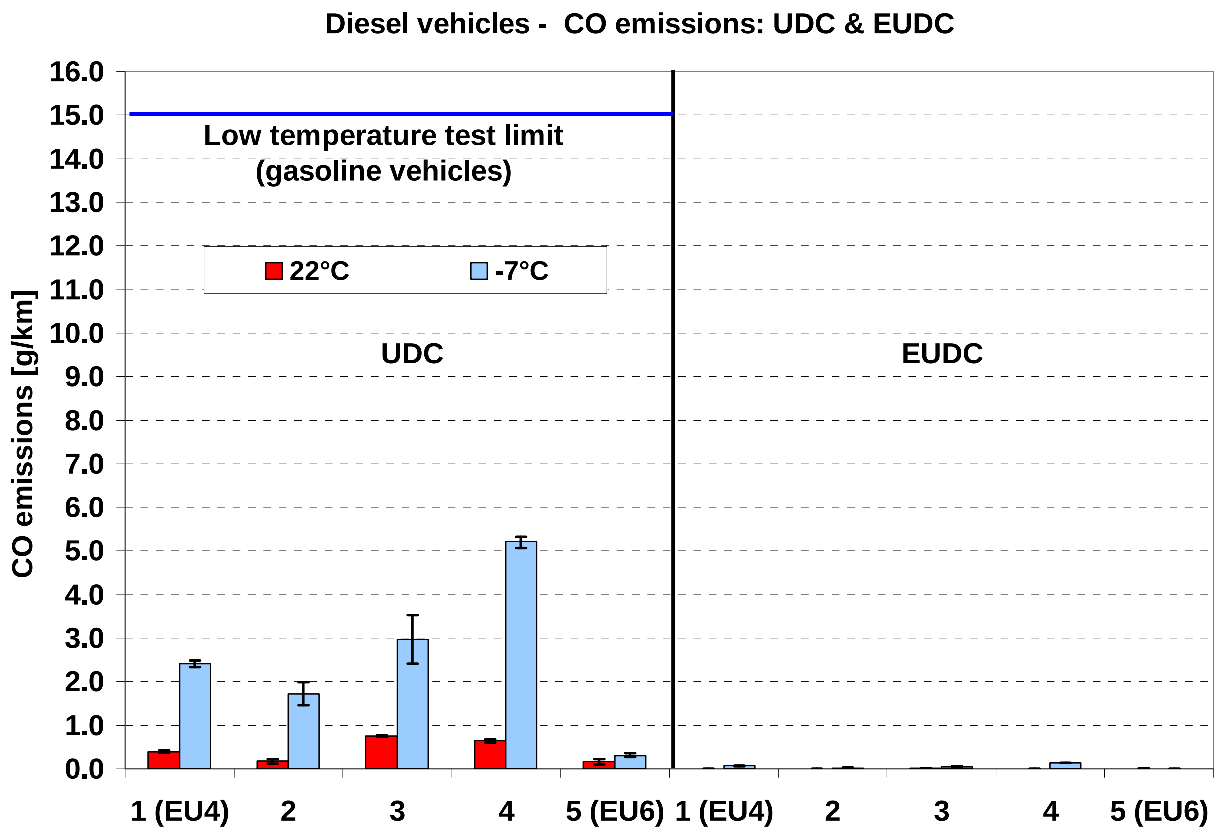


Figure 15 – CO bag emission values over the UDC (left panel) and EUDC (right panel) driving cycles at 22 and -7°C for the tested vehicles.

Figure 16 summarizes the results for total HC emissions. Also in this case, to allow a direct comparison the same scale has been used for both the UDC (left panel) and EUDC (right panel). Total HC from vehicles equipped with compression ignition engines are currently regulated only in combination with the NO_x emissions. However in this report the total HC emission will be assessed separately and compared with the emission limit valid for gasoline cars in the low temperature test, as also shown in Figure 16 with solid line at UDC part (1.8 g/km).

As for CO emissions, the total HC values measured over the urban part are much higher than the values measured over the EUDC.

In the low temperature test Vehicle 4 resulted the car with the largest increase of total HC emissions measured over the UDC (8.6 times) as well as the vehicle with the highest emission level (0.639 g/km). This value however is still 65% lower than the current limit valid for gasoline cars (1.8 g/km). All the other tested vehicles remained below 0.407 g/km of total HC over the UDC.

The total HC emissions over the extra-urban part of the cycle (EUDC) at low temperature conditions resulted to be very low compared to the urban driving conditions. Vehicle 4 was again the highest emitter with 0.086 g/km at -7°C over the EUDC.

The Euro 6 compliant Vehicle 6 exhibited the lowest total HC emissions and a very low sensitivity to the test temperature like in the case of CO.

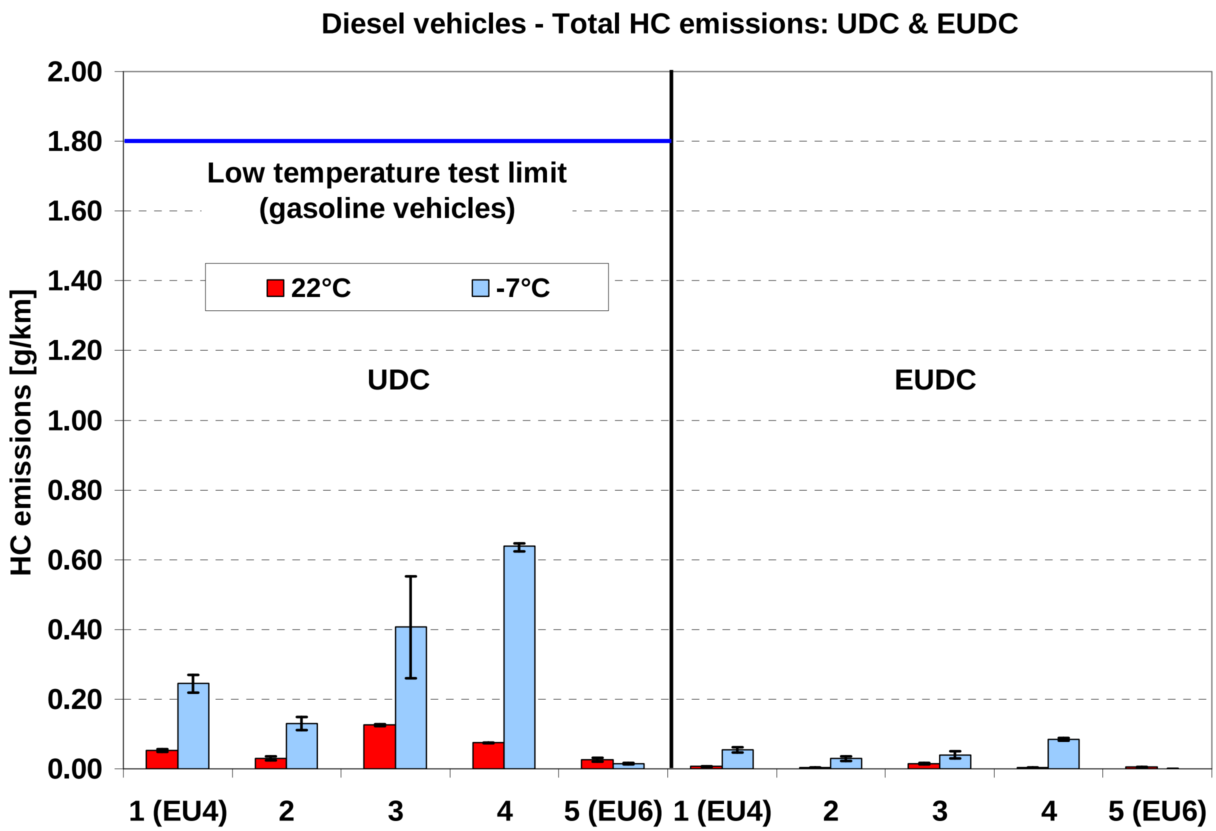


Figure 16 – Total HC bag emission values over the UDC (left panel) and EUDC (right panel) driving cycles at 22 and -7°C for the tested vehicles.

The fact that CO (and total HC) emissions over the NEDC are dominated by the cold start emissions and that NO_x is not currently regulated in the low temperature test justifies the choice of limiting the test to the UDC for gasoline cars. However, this choice might be not the most appropriate for diesel vehicles if NO_x emissions were included among the regulated pollutants. This issue will be discussed in the next paragraphs.

An overview of the NO_x emissions is provided in Figure 17 at both the temperatures (22°C and -7°C). Again, the same scale has been used in the plot referred to the tests performed over NEDC (left panel), UDC (central panel) and EUDC (right panel). The legislative Euro 4/5/6 limits for the Type I test are represented by solid lines (0.25, 0.18 and 0.08 g/km respectively, over NEDC). In general all the tested vehicles complied with the relevant NO_x emission limits. The average emissions of Vehicle 2 matched exactly the Euro 5 limit of 0.18 g/km.

In the low temperature test the emissions measured over the NEDC increased several times for all the vehicles with Vehicle 2 showing the largest increase (6 times) and the highest emission value (1.08 g/km). The vehicle with the second highest NO_x emissions at -7°C was the Euro 4 certified passenger car (Vehicle 1), with an average measured value of 0.784 g/km. The other Euro 5 certified vehicles (Vehicles 3 & 4) emitted 0.589 and 0.713 g/km respectively. The only Euro 6 passenger car that was tested in this programme showed instead the lowest NO_x levels emitting 0.367 g/km over the NEDC at -7°C.

If only the urban part of the NEDC is considered, Vehicle 2 is still the worst performing vehicle at -7°C with a 7.9-fold increase of NO_x emissions compared to the 22°C test, corresponding to 1.93 g/km. The Euro 4 compliant Vehicle 1 emitted 0.962 g/km while all the other tested vehicles remained below 0.821 g/km of NO_x over the UDC at -7°C.

The effect of the low temperature is evident also for the NO_x emissions measured over the EUDC with an increase ranging from 4.1 times (Vehicle 4) to 8.7 times for the Euro 6 car (Vehicle 5). The highest measured value was 0.68 g/km (Vehicle 1). As far the Euro 6 vehicle is concerned, the NO_x emissions measured over the EUDC at -7°C resulted to be the lowest (0.10 g/km) despite the large increase compared to the test at 22°C.

Interestingly, both at 22°C and -7°C the Euro 6 vehicle exhibited NO_x emissions over the UDC in line with the other vehicles while it performed much better over the EUDC. The much lower emissions over the EUDC explain the lowest NO_x emissions over the whole cycle. The low emissions over the EUDC might be due to the SCR converting efficiently NO_x to N_2.

For the non-Euro 6 vehicles (without any NO_x after-treatment system), the extra-urban part contributes noticeably to the total NO_x emissions and in some cases the emissions over the EUDC are almost at the same level as in the UDC. Nevertheless, the data presented in this report suggests that it might be sufficient to test the vehicle just over the UDC to keep under control the NO_x emissions at low temperature.

In fact, as already mentioned above, for all the vehicles tested the emissions (expressed in g/km) measured over the extra-urban part of the cycle are lower (or maximum at the same level) than the value measured over the UDC. Considering that the EUDC corresponds to a distance of 7 km and the UDC to 4 km, it is clear that in such situation the distance weighted emissions in g/km for the whole NEDC will in any case be lower than the UDC value. In other words, the value in g/km referred to the UDC represents the worst case and therefore testing the vehicle over the EUDC could not be strictly needed. This is especially true for the vehicles equipped with the SCR system since this device works satisfactorily only over the EUDC. However this conclusion needs to be supported by other data since only one Euro 6 vehicles was tested in this programme. Of course, if vehicles equipped with different after-treatment devices (e.g. lean NO_x traps) show a different behaviour and more specifically emissions over the UDC lower than over the EUDC, the above conclusion will not be valid anymore and the whole NEDC should be used.

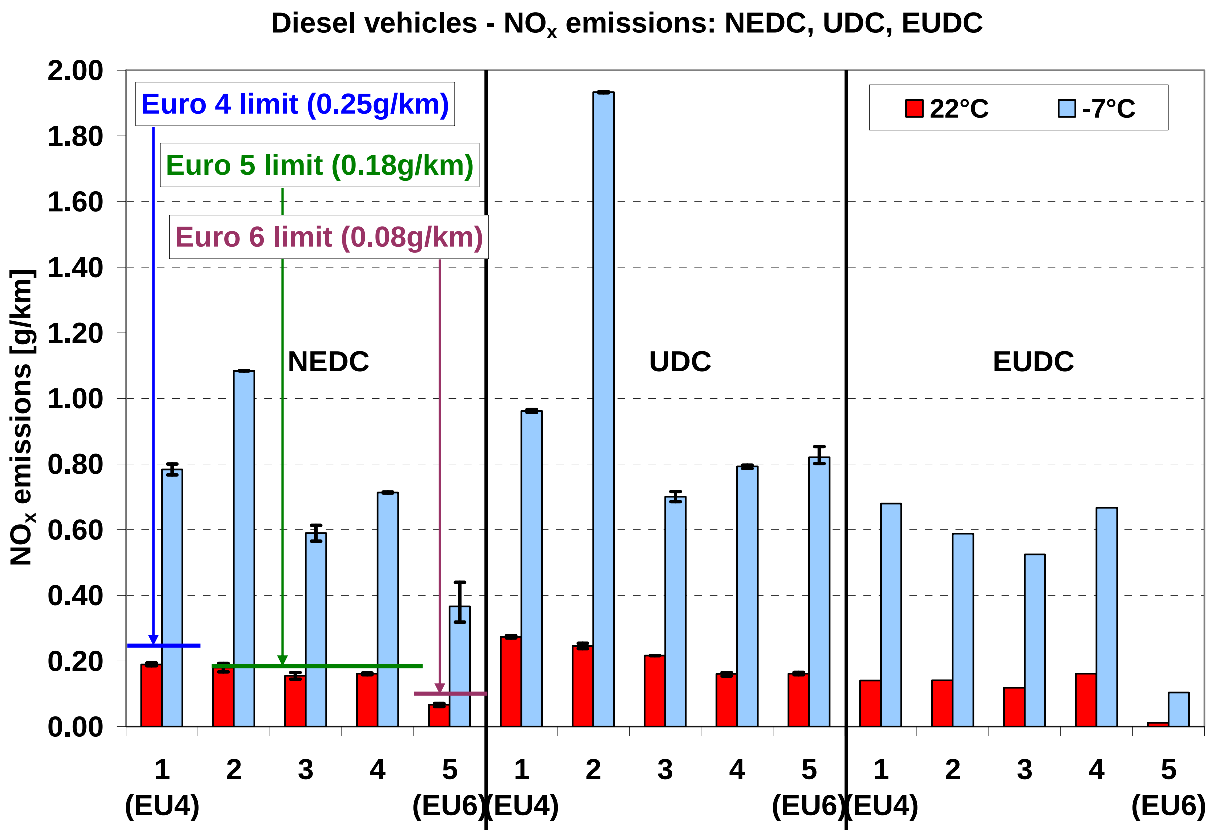
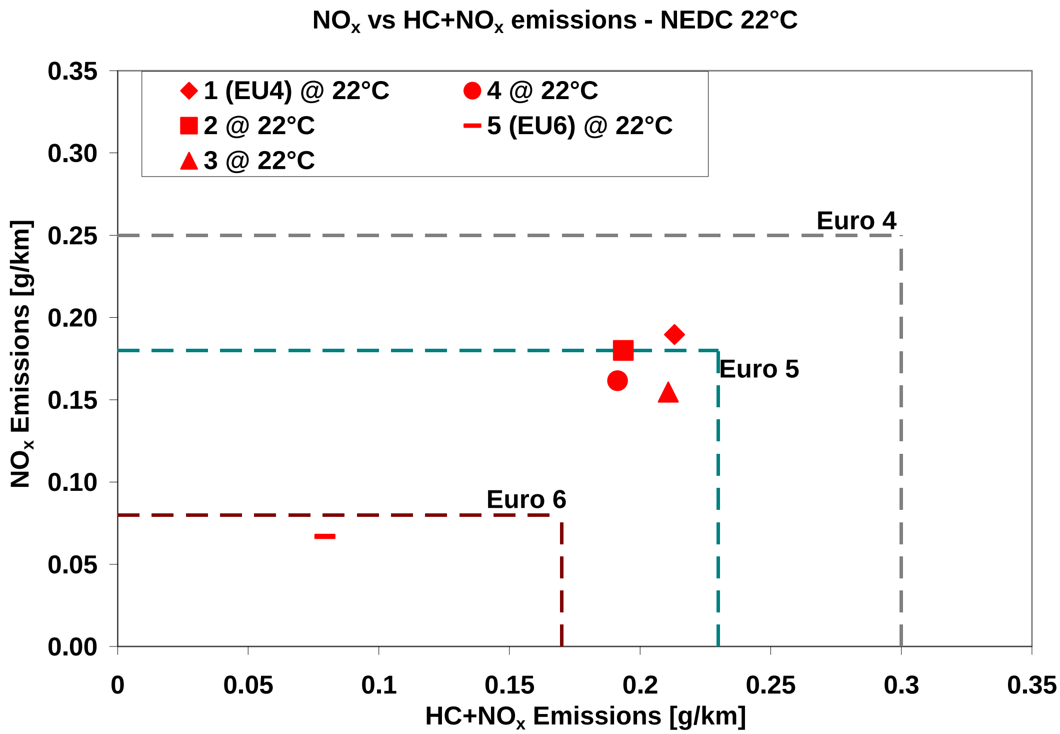


Figure 17 – NO_x bag emission values over the NEDC (left panel), UDC (central panel) and EUDC (right panel) driving cycles at 22 and -7°C for the tested vehicles.

The HC+NO_x combined emissions measured at the two different test temperatures (22 & -7°C) are plotted against the NO_x emissions in Figure 18 in x-y scatter chart. The relevant legislative Euro 4/5/6 emission limits referred to the NEDC at 22°C (Type I test) are represented with dashed lines. The second plot in Figure 18 shows the remarkable increase of the combined HC+NO_x emissions at -7°C, mainly reflecting the increase in NO_x emissions.



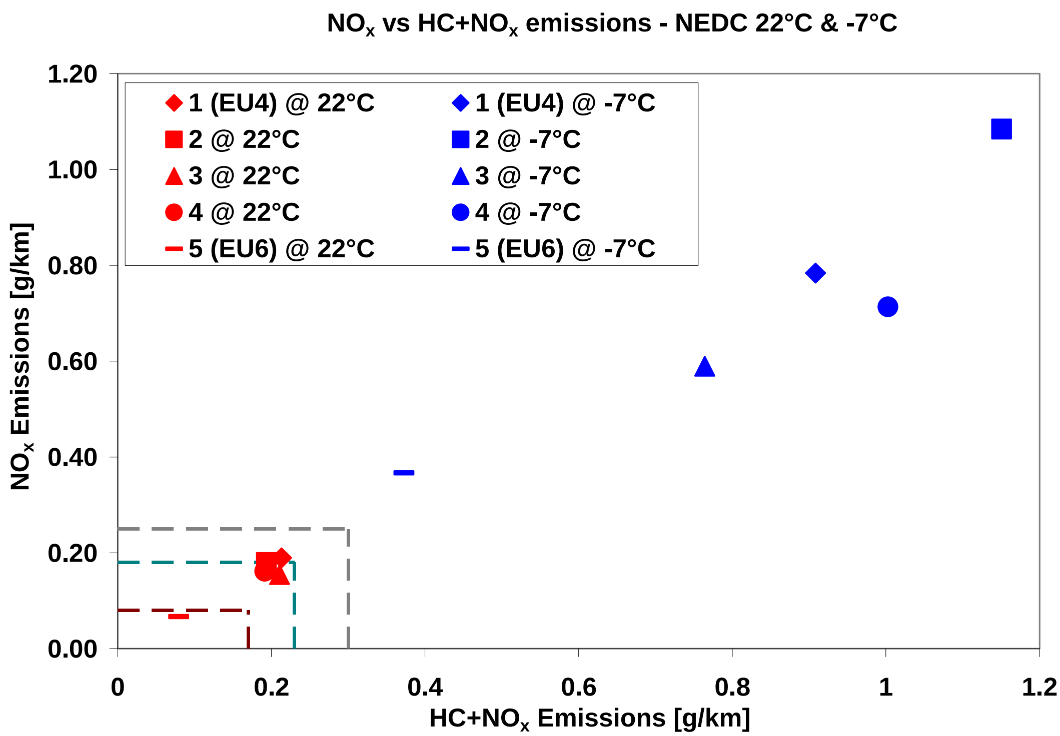


Figure 18 – NO_x and HC+NO_x bag emission values over the NEDC, UDC and EUDC driving cycles at 22 and -7°C for the tested vehicles.

Total particulate mass (PM) and particle number (PN) emissions have been also measured. Figure 19 presents the PM emissions of the tested vehicles. The error bars represent the minimum and maximum measures value. All the vehicles complied with the relevant limits. For Euro 5/6 compliant vehicles the use of diesel particulate filter reduced the PM emissions effectively. Vehicle 1 (EU4) emitted double PM emissions over NEDC at low temperature conditions.

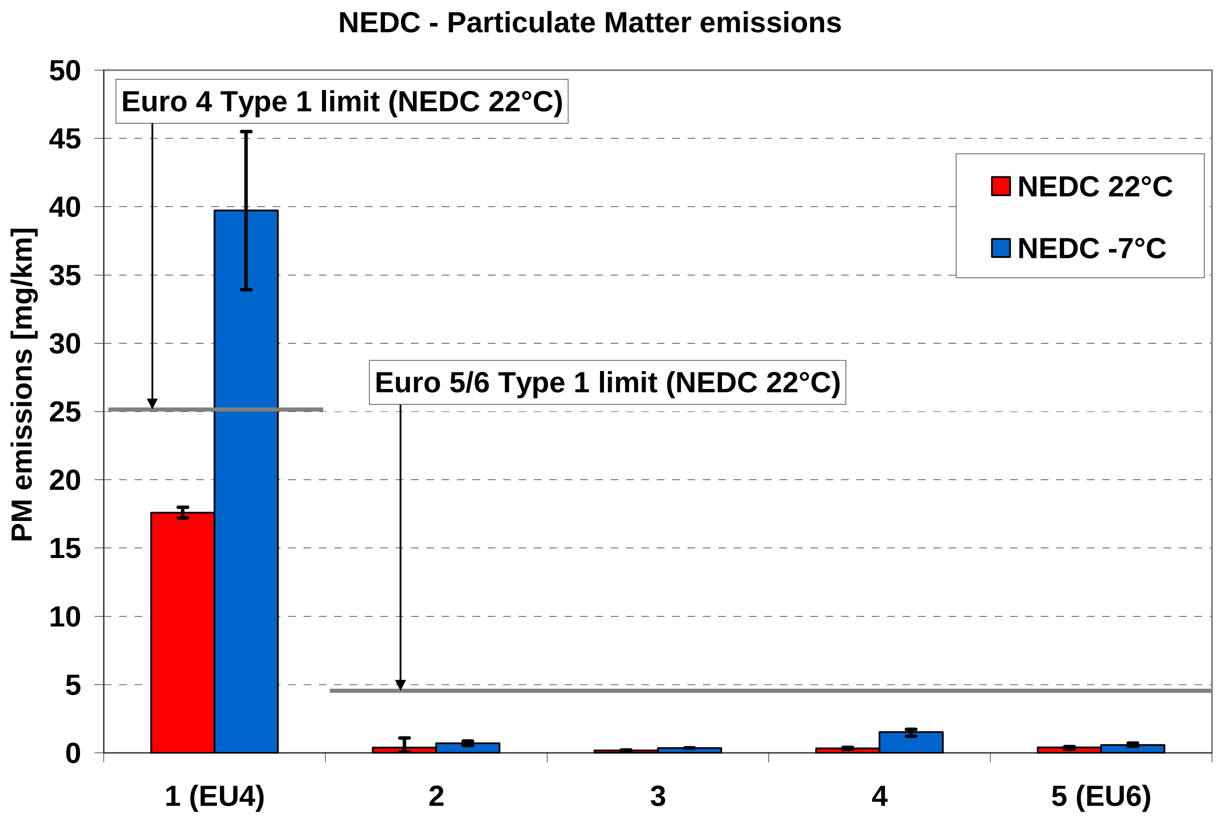


Figure 19 – Particulate Matter (PM) emissions at both temperature tests over NEDC for the tested vehicles.

Figure 20 shows the same as above results, excluding Vehicle 1 (EU4). In this case, the scale of y-axis changed, as all the presented vehicles were equipped with DPF, resulting in very low PM emissions. At 22°C the average PM emissions were below 0.5 mg/km, as all these vehicles were equipped with DPF. The PM emissions got double when the test conducted at -7°C for Vehicles 2 and 3. Vehicle 4 PM emissions increased 5 times, resulting on average at 1.5 mg/km over NEDC at low temperature conditions.

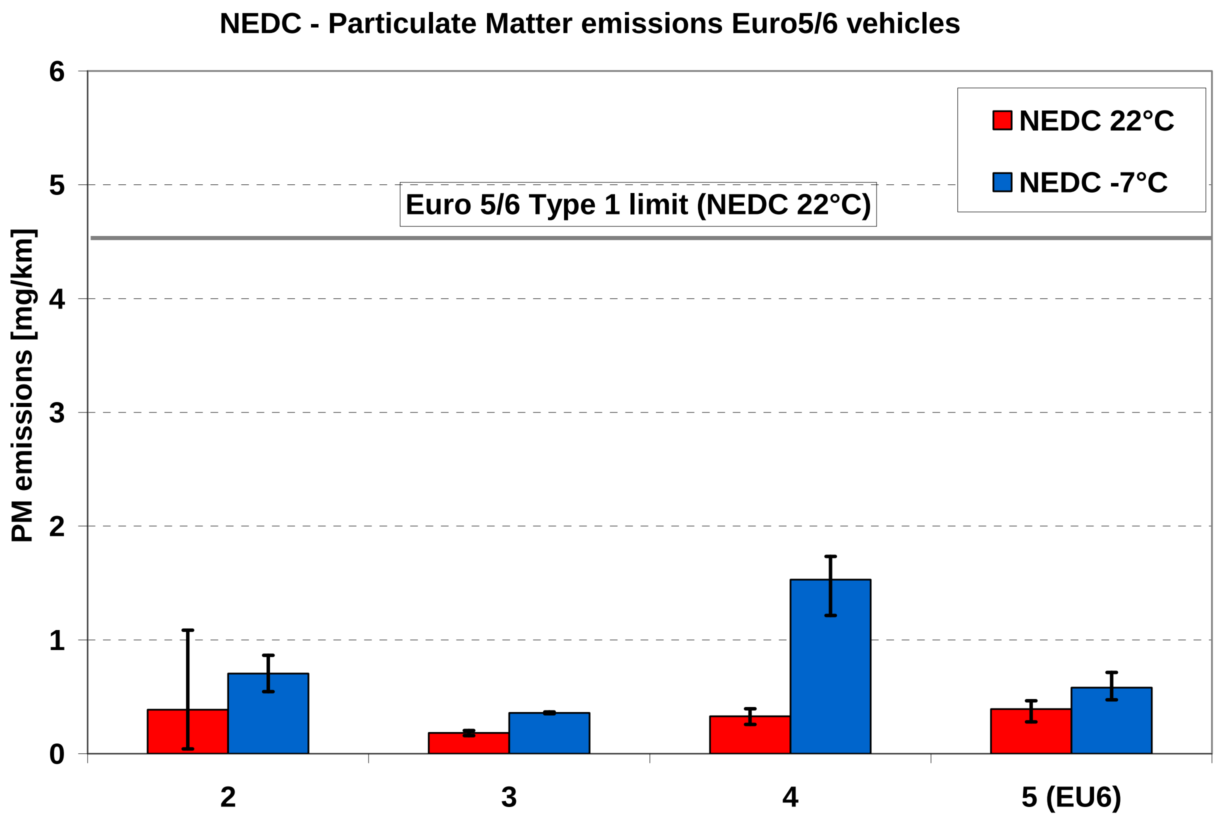
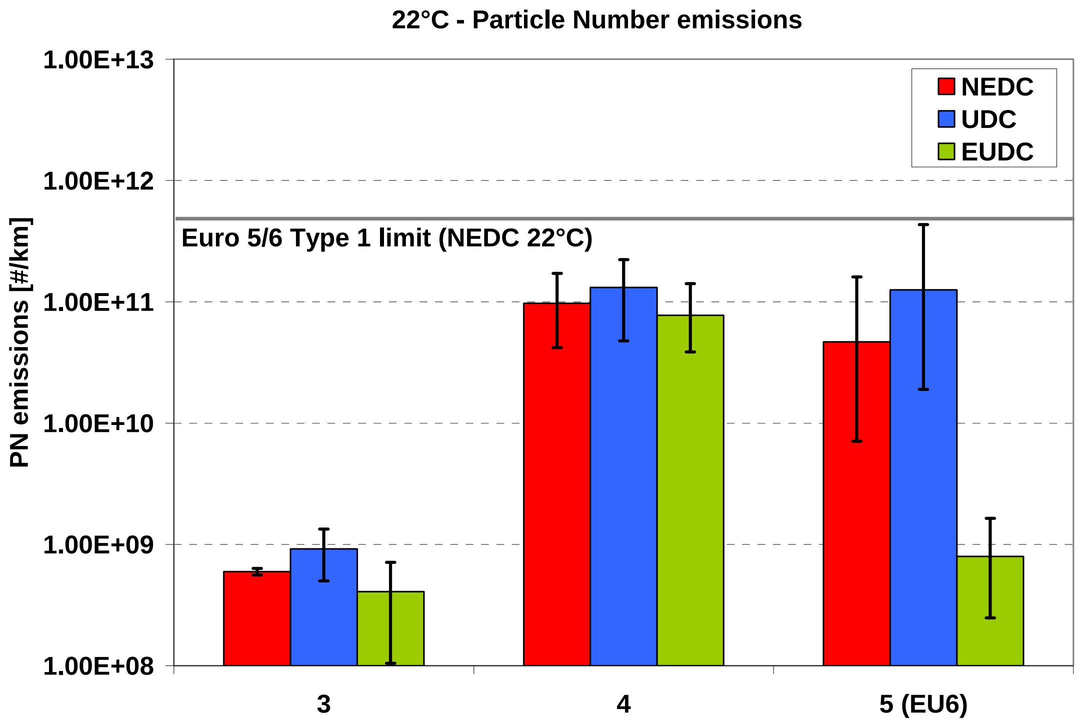


Figure 20 – Particulate Matter (PM) emissions at both temperature tests over NEDC for the Euro 5/6 tested vehicles.

Figure 21 presents the particle number emissions over NEDC, UDC and EUDC for Vehicles 3 to 5 in both temperature tests. Vehicle 3 PN emissions increased more than two orders of magnitude in low temperature conditions (from 5.97×10^8 to 1.63×10^{11} #/km). Vehicle 5 PN emissions increased one order of magnitude, while Vehicle 4 PN emissions resulted lower in low temperature test. For PM/PN emissions at low ambient temperature conditions, there is not always a straightforward trend. Several factors may lead the emissions to lower or higher concentrations, such as the engine load, the combustion characteristics, the EGR rate and the fill status of the porous DPF substrate. For an extensive study of particle emission see also a recent report from JRC [20].



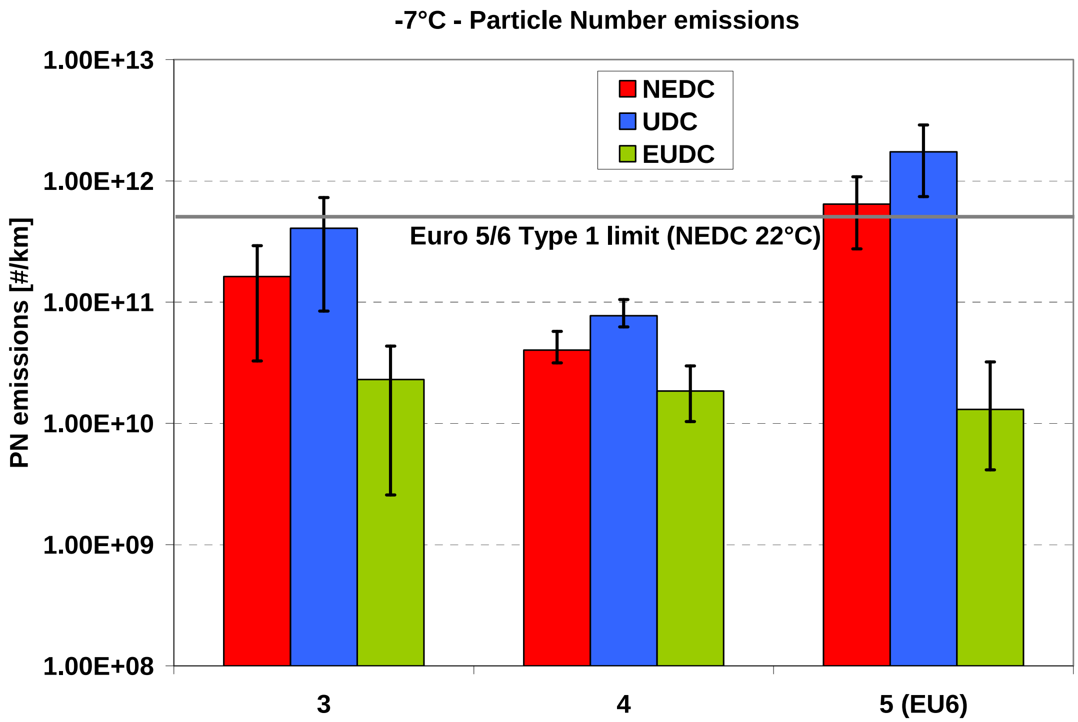


Figure 21 – Particle Number emissions over the NEDC, UDC and EUDC driving cycles at 22and -7°C for the tested Vehicles 3 to 5.

5 CONCLUSIONS

This final report provides a picture of the emission performances at low temperature of modern diesel vehicles. Euro 4/5/6 diesel passenger cars were tested at the Vehicle Emission Laboratory of the JRC in order to provide useful data for the discussion on a potential extension to this engine technology of the Type VI test (low temperature test, -7°C) currently required only for gasoline cars. In total one Euro 4, three Euro 5 and one Euro 6 vehicles were tested over NEDC driving cycle at 22 and -7°C test temperatures.

The main conclusions could be summarised as follows:

- The low temperature had the largest impact on CO and total HC mainly over the urban part of the cycle which includes the cold start. Compared to the values measured at 22°C, the Euro 4/5 vehicles exhibited significant increases (from 3.2 to 9.3 times) of both CO and total HC over the UDC. The highest emission levels measured over the UDC at -7°C were 5.2 g/km and 0.64 g/km for CO and total HC respectively (Vehicle 4). These values have to be compared with the respective limits for the Type VI test currently in force for gasoline vehicles (15 g/km for CO and 1.8 g/km for HC). Excluding Vehicle 4 that showed the highest emissions in the low temperature test, the emission of the remaining vehicles over the UDC at -7°C were below 2.97 (CO) and 0.407 g/km (HC). It should be reminded that for diesel vehicles in the Type I test total HC are only regulated in combination with NO_x emissions ($HC+NO_x$). The only Euro 6 compliant vehicle tested (Vehicle 5) exhibited the lowest CO and HC emissions both at 22°C and at -7°C. In addition in this case CO and total HC were almost unaffected by the test temperature.
- In the low temperature test NO_x emissions increased significantly both over the urban part (UDC) and over the extra-urban (EUDC) part of the NEDC. As far as the Euro 4/5 vehicles are concerned, the highest NO_x value measured over the NEDC at -7°C was 1.084 g/km (Vehicle 2) with an increase of 6 times compared to the value measured on the same vehicle at 22°C. The NO_x emissions of the Euro 6 vehicle (Vehicle 5) resulted to be the lowest at 22°C (0.067 g/km over NEDC). At -7°C the NO_x emissions of the same vehicle over the NEDC increased to 0.367 g/km, still the best performance if compared to the other Euro 4/5 cars. However, if only the UDC is considered, both at 22°C and at -7°C the Euro 6 car exhibited NO_x emissions more or less in line with the Euro 4/5 vehicles. The lower NO_x emissions over the NEDC have to be attributed to EUDC part where thanks to the SCR the emissions were effectively reduced to very low levels.
- As for gasoline cars, also for the tested diesel vehicles CO and total HC emissions measured over the NEDC were dominated by what had been emitted during the first part of the cycle (UDC). The situation is quite different for NO_x emissions: In this case, the extra-urban part contributes noticeably to the total NO_x emissions and in in some cases the emissions over the EUDC are almost at the same level as in the UDC. However, the data presented in this report suggests that for regulatory purposes it might be sufficient to test the vehicle just over the UDC, to keep under control also the NO_x emissions at low temperature. In fact, since for all the vehicles tested the emissions expressed in g/km over the extra-urban part of the cycle turned out to be lower (or maximum at the same level) than the value measured over the UDC, the latter value represents the worst case. This is especially true for the vehicles equipped with the SCR system since this device works satisfactorily only over the EUDC. However this conclusion needs to be supported by other data since only one Euro 6 vehicles was tested in this programme. Of course, if vehicles equipped with different after-treatment devices (e.g. lean NO_x

traps) show a different behaviour and more specifically emissions over the UDC lower than over the EUDC, the above conclusion will not be valid anymore and the whole NEDC should be used.

6 LIST OF SPECIAL TERMS AND ABBREVIATIONS

CO	Carbon Monoxide
CO_2	Carbon Dioxide
CR-DI	Common Rail Direct Injection
CVS	Constant Volume Sampler
DOC	Diesel Oxidation Catalyst
DPF	Diesel Particulate Filter
UDC	Urban Driving Cycle (Part 1 of the NEDC driving cycle)
EGR	Exhaust Gas Recirculation
EU/Euro #	European Emission Standard
EUDC	Extra-Urban Driving Cycle (Part 2 of the NEDC driving cycle)
HC	Hydrocarbon
JRC	Joint Research Centre
NEDC	New European Driving Cycle
NO_x	Oxides of Nitrogen (NO & NO_2)
O_2	Oxygen
PM	Particulate Matter
PN	Particle Number
SCR	Selective Catalytic Reduction
VELA	Vehicle and Engine Emission Laboratories

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Abstract
The European Commission Regulations No 692/2008 and No 715/2007 set the regulatory framework for type-approval of motor vehicles with respect to emissions from light passenger and commercial vehicles (Euro 5/6). One of the applicable tests is the low temperature emission test (Type VI), which is conducted at sub-ambient temperature conditions (-7°C).
The low temperature emission test is currently required only for vehicles with positive ignition engines. However the Type VI test to diesel vehicles is under consideration, mainly because of the introduction of the new technologies in diesel engines in order to comply with the Euro5/6 emission standards, of which the efficiency in controlling emission may strongly depend on the ambient temperature. This is especially true for Exhaust Gas Recirculation (EGR) systems and after-treatment systems for Oxides of Nitrogen (NO_x) that are deactivated or not operate in cold weather conditions, may result in elevated NO_x emissions. The review should consider whether to extend the low temperature emission test to Euro 6 diesel vehicles and whether emission limit should be introduced in the future.
This report provides a picture of the low temperature emission performances of late technology diesel vehicles The main results of the experimental activity carried out at JRC to investigate the behaviour at low temperature of Euro 5/6 diesel passenger cars are summarised and discussed.

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